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EVALUATION OF PORTABLE CARBON DIOXIDE ANALYZERS FOR USE AT 1-ATA ON U. S. NAVY SUBMARINES

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TECHNICAL REVIEW AND APPROVAL

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The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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13. ABSTRACT *(Maximum 200 words)*

The Naval Medical Research Institute (NMRI) was tasked by the Naval Submarine Medical Research Laboratory (NSMRL) in August 1994 to evaluate portable carbon dioxide analyzers for use at 1 ATA on U.S. Navy submarines. A plan for selection and testing of candidate analyzers was developed by NMRI and approved by NSMRL prior to start of work. Candidate analyzers were chosen based on desired requirements, market search, and preliminary testing. Five candidates were selected to undergo the following testing: precision, short-term accuracy, long-term (up to 90 days) accuracy, and effect of interfering gases and ambient temperature. Based on testing results, a non-dispersive infrared instrument, CDM-1000/long, manufactured by Geotechnical Instruments, Inc., is recommended as the best candidate for use on Navy submarines.

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BACKGROUND

The Naval Medical Research Institute (NMRI) was tasked by the Naval Submarine Medical Research Laboratory (NSMRL) in August 1994 to evaluate portable carbon dioxide (CO_2) analyzers for use on U.S. Navy submarines. These analyzers would be used at normal submarine pressures (i.e., ~ 1 ATA) to measure CO_2 levels in air throughout shipboard spaces. Such analyzers would supplement the current CAMS-I, the on-board gas analyzer, which is limited to a specific number of sampling sites and not designed to measure low CO_2 concentrations (e.g., < 0.2%). These instruments could also replace the CO_2 detector tubes that are used on a weekly basis but are not known to be very reliable.

EVALUATION PLAN

A plan for selection and testing of candidate analyzers was developed by NMRI and approved by NSMRL prior to start of work. This plan included the requirements of the desired analyzer, as well as detailed procedures for evaluating performance.

Requirements

1. *Essential*

a. Measurement range: 0 to 7.5% CO_2 (sub escape limit); may require more than 1 instrument to span range.

b. Ambient Temperature range: 20 to 40 °C.

c. Interferences: accuracy limits met with sample concentrations of total hydrocarbons up to 90-day limit and CO, hydrogen, and Freons up to 1 h limits.

2. *Desired but non-essential*

a. Short-Term Repeatability (within 10 min): ± 5% relative over range 0.1% to 7.5% CO_2.

b. Short-Term Accuracy (within 10 min of calibration): ± 10% relative over range 0.1% to 7.5% CO_2.

c. Long-Term Accuracy (up to 90 days after calibration): ± 25% relative over range 0.1% to 7.5% CO_2.

d. Response time: less than 30 s to 95% of reading.

e. Physical dimensions: volume less than 0.5 cubic foot.

f. Task appropriate: rugged, corpsman friendly, low cost.

Selection of candidate analyzers

Candidate analyzers would be selected based on a market search, manufacturer specifications, demonstrations, and preliminary testing by NMRI.

1. *Market search.* The market search consisted of a review of product literature obtained from vendors, attending of analytical exhibits at meetings, and requested demonstrations by vendors.

2. *Preliminary testing.* Such testing was performed by NMRI at in-house demonstrations by vendors and using loaned units.

3. *Selection.* **Appendix A** provides detailed information regarding instruments reviewed resulting in 5 candidate analyzers being chosen for formal testing by NMRI. All use non-dispersive infrared detection as their method of analysis. The 5 analyzers are listed below:

a. Model CD-1300-P, Enmet Corp.

0 to 10% CO_2

Analog readout

Zero and span adjustment

b. Model RIKEN RI-411A, RKI Instruments, Inc.

0 to 9.95% CO_2

Digital readout

Zero and span adjustment

Fixed scale, X.XX (last decimal last reads in 0.05 increments)

c. Model 302 BD, NOVA Analytical Systems, Inc.

0 to 10% CO_2

Digital readout

Span adjustment, no zero adjustment

Fixed scale, X.X

d. Model CDM-1000/long, Geotechnical Instruments, Inc.

0 to 7.5% CO_2

Digital readout

Span adjustment, no zero adjustment

Variable scale, X.XXX for 0 to 0.999, X.XX for 1.00 to 8.00

Long = long pathlength cell

e. Model CDM-1000/short, Geotechnical Instruments, Inc.

0 to 7.5% CO_2

Same specifications as CDM-1000/long

Short = short pathlength cell

To facilitate discussion, these analyzers will be referred to in this report as Enmet, RKI, Nova, GeoL, and GeoS, respectively.

Summary of testing procedures

One of each of the 5 candidate analyzers was tested for the following:

1. *Precision* (short-term repeatability)

Calibrated instruments were presented with the same mixture multiple times over a 10-minute period and variability noted. This was done with a range of CO_2 concentrations and on multiple occasions.

2. *Short-term accuracy*

Calibrated instruments were presented with a range of mixtures over 20-30 min and the difference noted between actual value and measurement. This reflected both precision and linearity of instrument and was also limited by error in the test gases. The longer test time vs. the initial 10-minute requirement was necessary as complete concentration-response curves were generated as discussed below.

3. *Long-term accuracy*

Short-term accuracy tests were repeated up to 90 days without re-calibration. This reflected short-term accuracy and long-term drift of instrument calibration (i.e., zero and gain).

4. *Interfering gases*

Precision and short-term accuracy tests were repeated with a range of CO_2 calibration mixtures containing carbon monoxide, hydrogen, Freons, and aromatic and aliphatic hydrocarbons. Interfering gas concentrations were chosen based on 1-hour submarine limits for the first 3 species and 90-day limits for the hydrocarbons, as 1-hour limits have not been established.

5. *Ambient temperature*

Effect of ambient temperature on analyzer measurement was examined from ~10 °C to ~35 °C.

6. *Field testing*

Determination of suitability for use in submarine environments and degree of "sailor friendliness" was made by field testing on 1 submarine.

7. *Interpretation of results*

Pass/fail criteria for analyzer performance is given under Requirements section above. Criteria for judging suitability for use by submariners and use in a submarine environment were based on Requirements and also included feedback from field testing.

METHODS

All laboratory testing, except that under the section Ambient Temperature, was done at temperatures normally between 19 and 24 °C. However, during the latter part of the long-term accuracy test, laboratory temperatures occasionally ranged up to 30 °C due to air conditioning problems. Changes in barometric pressure were ignored.

Laboratory testing

The following gases were used during testing:

Zero gas: CO_2-free, hydrocarbon-free air.

Span gases: Four primary gravimetric standards: 0.25%, 2.5%, 5.0%, and 10% CO_2, all in balance hydrocarbon-free air and certified to $\pm$ 1% relative.

Gas was delivered to the analyzers using a precision gas divider (STEC model SGD-710, Horiba Instruments, Inc., Ann Arbor, MI). The STEC device allowed blending of the 4 CO_2 standards with a diluent gas (hydrocarbon-free air) in 10 equal steps from 0 to 100% of the original CO_2 concentration. This divider has been previously shown to be linear to within the manufacturer's specification of $\pm$ 0.5% of full scale, using 5 to 100 ppm levels of a number of volatile organic compounds (**1-2**) and up to 25% of fixed gases (e.g., O_2, CO_2). In this way, accuracy of analyzers could be tested over entire calibration curves (0 to 100% of each test mixture) rather than only at the 4 concentrations of the mixtures. The only exception was for the 10% CO_2 gas where the maximum STEC setting used was 80% resulting in a maximum CO_2 concentration of 8%. The Enmet and Nova analyzers were not tested with the lowest CO_2 standard, 0.25%, as the first instrument's analog display did not resolve such low concentrations and the second instrument's digital display did not go below 0.1%.

Teflon tubing was used to connect the standards and diluent gases to the STEC. Wide-bore (1/4-inch inner diameter) Tygon tubing containing a tee was used to deliver gas to the inlet port of the analyzer. Gas flow was adjusted so that a slight excess flow was delivered resulting in several liters/min leaving the overflow (**Fig. 1**). In this manner, gas was sampled without pressurizing the instrument.

1. *Precision*

a. Instrument was turned on and allowed warmup time per instrument manual.

b. Instrument was calibrated per instructions in manual. Hydrocarbon-free gas was used as the zero gas where zero gas was required. One of the four 4 CO_2 standards was used as the span gas with STEC at 100% (except STEC = 80% for 10% CO_2 standard).

c. One minute was waited.

d. Zero gas was sampled and measurements taken when stabilized.

e. Span gas was sampled and measurements taken when stabilized.

f. Steps d-e were repeated every 2 min for a total of 5 times during which calibration controls were not touched.

g. Steps b-f were repeated for the other 3 CO_2 standards.

h. This test was done at the beginning of each short-term accuracy test (below).

2. *Short-term accuracy*

a. Instrument was turned on and allowed warmup time per manual.

b. Instrument was calibrated per manual using 1 of the 4 span gases and zero gas (if required).

c. One minute was waited.

d. STEC setting was varied from 0 to 100% of span gas and back to 0% (0 to 80% and back to 0% of span for 10% CO_2 standard) and measurements taken when stabilized.

e. Steps b-d were repeated for the other 3 CO_2 standards.

f. This test was run weekly for a total of 4 weeks.

g. Minimum test concentration was 0.025% CO_2 (STEC=1 for 0.25% CO_2).

3. *Long-term accuracy*

a. This testing was started after all precision and short-term testing had been completed.

b. Testing, as per short-term accuracy, was repeated weekly for a total of 13 weeks, but analyzer was calibrated only once at the start of the first week's test using 8% CO_2.

4. *Interfering gases*

a. Precision and short-term accuracy testing were repeated using each of the following 5 gravimetric standards, all prepared in hydrocarbon-free air, as the diluent gas for STEC:

(1) ~1000 ppm CO

(2) ~1% Hydrogen

(3) ~3000 ppm Freon 114

~3000 ppm Freon 12

(4) ~10 ppm Toluene

(~38 mg/m^3)

(5) ~50 ppm Octane

(~230 mg/m^3)

The listed concentrations are the nominal values that were certified to ± 2% of reported values.

b. These gases were chosen based on the following limits from the Submarine Atmosphere Control Manual (**3**):

	Limits	
	1 hour	90 day
Carbon monoxide	400 ppm	
Hydrogen	1%	
Freon 12	2000 ppm	
Freon 114	2000 ppm	
Total aromatic hydrocarbons (less Benzene)	NE	10 mg/m^3
Total aliphatic hydrocarbons (less methane)	NE	60 mg/m^3

NE = limit has not been established.

c. As the STEC setting was varied from 0 to 100%, the resulting interfering standard concentration in the gas going to the analyzer would change from 100 to 0% of its prepared value. In this way, contaminant concentrations would bracket the actual submarine limits given above.

d. No effect by the testing setup (e.g., absorption by the tubing) on the volatile organic mixtures (Freons, octane, and toluene) was detected. This was shown by sampling gas upstream and downstream of the setup using the TVA-1000 portable toxic vapor analyzer (Foxboro Co., East Bridgewater, MA).

e. To expedite completion of our study, this test was done once during the period when long-term accuracy testing was being done.

5. *Ambient temperature*

a. All 5 instruments were turned on and allowed to warm up for 15 min.

b. Instruments were calibrated with 8% CO_2 at laboratory temperature (19-21 °C).

c. Analyzers were placed into a small animal hyperbaric chamber which was at laboratory temperature, and the door closed although not sealed to hold pressure.

d. A hull penetrator allowed gas to be delivered to the instruments in usual fashion. Chamber temperature was regulated to ± 0.5 °C using a temperature-controlling unit (Yellow Springs Instrument Co., Yellow Springs, OH).

e. Initial instrument readings were taken for zero air and 8% CO_2 at laboratory temperature by looking through the chamber viewport.

f. The temperature controller was adjusted to maximum cooling or heating and allowed to stabilize for 2 h.

g. Measurements were then taken again for zero air and 8% CO_2.

h. The temperature controller was then adjusted to the maximum opposite setting, and after 2 h, measurements were again taken.

i. The controller was then set back to room temperature, and measurements were repeated after 2 h.

j. Five complete tests were done on separate days with all analyzers tested together:

(1) Two tests going first to cold and then to hot

(2) Two tests going first to hot and then to cold

(3) One test remaining at laboratory temperature for 6 h as a control.

k. Minimum and maximum chamber temperatures that could be obtained with the NMRI setup were ~10 °C and ~35 °C.

Field testing

Field testing of the recommended instrument was done by ship's personnel on the USS James K. Polk (SSN-645) during a 19-day period from 13 September to 1 October 1995. During this period, the submarine went out to sea twice. Detailed procedures are given in

Appendix B.

This testing was designed to evaluate:

1. Stability of the instrument under actual submarine conditions.

2. Potential problems with the draft operating procedures.

3. How the CO_2 measurements of the analyzer compare to those from the CAMS-I.

4. Sailor "friendliness" of the instrument.

To summarize procedures, the analyzer was calibrated with 8% CO_2 at NMRI on 8 August 1995 prior to delivery to the submarine. During the actual field test, analyzer calibration was checked, but not recalibrated, once daily prior to use by measuring the CAMS-I calibration gas mixture (containing ~1.3% CO^2) carried on all submarines. Following the calibration check, CO_2 measurements were taken with the analyzer once at up to 11 locations on the submarine that could also be sampled by the CAMS-I. Analyzer and CAMS-I (CO_2 and total pressure) measurements were taken simultaneously by using 2 people and shipboard communication. Analyzer readings were recorded when stable with the instrument positioned immediately next to the inlet of the CAMS-I sampling line.

Analyzer measurements were not corrected for the small changes in total pressure on the submarine. CAMS-I CO_2 and total pressure readings were displayed and recorded to the nearest 0.1 and 1 torr respectively. CAMS-I percent CO_2 was calculated as follows:

$$\%CO_2 = \frac{\text{CAMS-I } CO_2 \text{ (torr)}}{\text{CAMS-I pressure (torr)}} \bullet 100$$

Following the field test, the analyzer was returned to NMRI where instrument response to 0 to 8% CO_2 was determined, both before and after recalibration with 8% CO_2, using the

STEC device.

Data analysis

Means and relative standard deviations were calculated from the precision data. Short-term and long-term accuracy data were used to calculate relative percent error:

$$\text{Relative percent error} = \frac{\text{Observed reading - Expected reading}}{\text{Expected reading}} \bullet 100$$

Expected reading was determined by multiplying the certified value of the CO_2 standard by the STEC setting (i.e., 0 to 100%).

As discussed above, testing with interfering gases was done during the same period as long-term testing, making re-calibration prior to testing impossible. Therefore, the gas effect was judged by calculating the difference between the measurement errors while using the interfering gases and the errors determined during the long-term test done the same week.

For Ambient Temperature data, instrument drift during cold and hot exposures was calculated relative to the initial lab temperature in the following manner:

$$\text{Drift } (\%CO_2/°C) = \frac{\text{Reading at test temperature (cold or hot) - Initial reading}}{\text{Test temperature - Initial lab temperature}}$$

$$\text{Percent Drift } (\%/°C) = \frac{\text{Drift} \bullet 100}{\text{Initial reading}}$$

RESULTS AND DISCUSSION

Precision

Results are given in **Table 1**. Some data for the lower concentration gases are missing from the table for the following reasons: a) the Enmet and Nova instruments were not tested

with the lowest concentration standard for reasons given above and b) problems arose with acquisition of some of the gases and some of the instruments at the start of this study.

With the exception of the Enmet with analog readout, relative standard deviations based on 5 measurements over 10 min was ≤ 2% for all instruments down to 2.5% CO_2. No problem with zero drift was observed with any instruments.

Conclusion: All analyzers, except the Enmet, met the 5% precision requirement using 2 relative standard deviations as an index of precision.

Short-term accuracy

All analyzers, with the exception of the Enmet, had a relative error of ≤ 10% for measurements from 8% down to ~1%. (**Table 2; Fig. 2**). Calibration with lower concentration standards improved measurement at lower levels. The GeoL and GeoS worked well (± 10%) down to ~0.25%, although at these levels small absolute errors translated into large relative errors. No problem with zero drift was observed with any instruments.

Representative response curves for each instrument for the 4 CO_2 standards are given in **Fig. 3**. As testing took place immediately after calibration, these curves would represent the "best-case" in terms of error.

Conclusion: The GeoL and GeoS analyzers were the best analyzers in terms of meeting the 10% accuracy requirement from 8% down to ~0.25%. The Enmet did not meet the requirement, even at the higher concentrations.

Long-term accuracy

All analyzers, except the Enmet, completed the long-term testing over 13 weeks (**Table 2**). The Enmet was eliminated from the test after 11 weeks after repeatedly exceeding the

25% accuracy requirement. All instruments, except the Enmet, met the accuracy limit at concentrations from 8% down to ~0.5-1%. No problem with zero drift was observed with any instruments. Procedural error during Week 6 resulted in loss of data and calibration in the GeoL and GeoS. Consequently, both instruments were re-calibrated prior to Week 7's test. **Fig. 4** summarizes the data well and suggests negligible effect of re-calibration on the test (i.e., compare Weeks 6 and 7 results). The clear leader in terms of long-term accuracy is the GeoL. The GeoL met the accuracy requirement down to concentrations < 0.05%, quite a remarkable feat.

Conclusion: The GeoL was clearly the best analyzer in terms of long-term accuracy following a one-time initial calibration with 8% CO_2.

Interfering gases

Differences between measurement errors with and without interfering gases were generally < 10% for the 4 instruments tested. This error is similar to short-term accuracy and thus an effect due to any of the 5 gases could not be detected. The ability to detect small effects due to gas was limited by doing this testing during the long-term accuracy test period when calibration was not permitted. However, any such effects should be inconsequential in terms meeting the relatively liberal accuracy requirements. The Enmet was not tested as it had been excluded after failure during the long-term accuracy test.

Conclusion: All 4 analyzers appeared to be unaffected by the interfering gases.

Ambient temperature

All instruments showed temperature drifts up to ± 0.2% CO_2/°C, which translate to ± 3% of the test concentration reading (**Fig. 5**). This effect dropped to ± 0.1% CO_2/°C and

± 1% of test reading if the Nova analyzer is omitted. The Enmet instrument was not tested, as it had been eliminated from the study by the time this last phase was done. Average starting, cooling, and heating temperatures were approximately 20 °C, 12 °C, and 34 °C. During the control test where ambient temperature was held constant (20.0 °C ± 0.5), analyzer measurements changed from starting values up to ± 0.3% CO_2 over 6 h. No problem with zero drift was observed with any instruments.

Conclusion: The RKI, GeoL, and GeoS responded to changes in ambient temperature similarly. The Nova was slightly more responsive to heating and cooling which would be a negative factor against its selection. Calibration of any of the first 3 instruments at normal room temperatures (18-24 °C) should result in acceptable accuracy when used at ~10 to 35 °C.

Field testing

During the 10 days of actual testing, daily measurement of the 1.353% CO_2 CAMS-I calibration gas using the recommended instrument (GeoL, see below) ranged from 1.350 to 1.420% CO_2. CAMS-I measurements from the various compartments of the submarine ranged from 0.27 to 1.02% CO_2 with total pressure within the various compartments from 747 to 791 torr. Differences between CAMS-I and GeoL measurements ((CAMS-I) - GeoL) ranged from -0.14 to 0.08% CO_2. On average, CAMS-I values were 0.05% CO_2, or ~9% of reading, lower than those of the GeoL.

NMRI testing following return of the instrument suggested that a shift in the calibration of the analyzer had occurred. This shift resulted in relative error lowest when measuring 1% CO_2 and increasing up to ~18% error as the CO_2 in the test gas was raised to 8%. Such performance would be expected if the instrument had been recalibrated with the

1.3% CO_2 CAMS-I calibration gas sometime during the field test. Ship's personnel indicate this had not occurred. Additional field testing would be needed to resolve this issue and determine if long-term accuracy as measured in the lab is a reliable measure of long-term accuracy in the field.

Ship's personnel reported no problems with the GeoL and were very enthusiastic about it.

Conclusion: The GeoL, the recommended analyzer, performed well during field testing although a shift in the calibration appears to have occurred during the test. Additional field testing would be needed to clarify this issue.

SUMMARY AND RECOMMENDATIONS

All 5 candidate analyzers completed all aspects of the original test plan. It is emphasized that recommendations are based on testing results from only 1 analyzer from each of the 5 candidates.

The Enmet unit failed the precision, short-term, and long-term accuracy tests and was difficult to calibrate. It had intermittent periods in which it did not operate at all and was rejected as unreliable.

The RKI unit was not as accurate over the long term as the GeoL and GeoS, but met all of the test requirements. It is easy to calibrate and to use.

The Nova unit is considerably larger than the others, but has excellent performance characteristics. Calibrating this analyzer requires patience and a short learning curve. Once mastered, it can be easily done. The major objection is that it is bulky to handle. It passed all

of the test requirements, although its response to ambient temperature is greater than the other analyzers.

Two 0 to 7.5% Geotechnical units were tested, one with a long pathlength cell (GeoL) and one with a short pathlength cell (GeoS). Both analyzers performed flawlessly. Operation is simple and calibration is easy. The size and weight are both good. The instruments met all of the test requirements. The GeoL had better accuracy at the lowest concentrations and is recommended as the best candidate for use on U.S. Navy submarines. The GeoL performed well during field testing, although additional testing is recommended.

Operating procedures for the recommended analyzer

Operating procedures for the recommended analyzer, Geotechnical CDM-1000/long are given in **Appendix C.**

REFERENCES

1. Lillo, R.S., Caldwell, J.M. Preliminary evaluation of a halogen leak detector for screening divers' breathing air. NMRI Technical Report No. 89-108, Naval Medical Research Institute, Bethesda, MD, 1989.

2. Lillo, R.S., Ruby, A., Gummin, D.D., Porter, W.R., Caldwell, J.M. Analysis of volatile contaminants in U.S. Navy fleet soda lime. NMRI Technical Report No. 95-39, Naval Medical Research Institute, Bethesda, MD, 1995.

3. U.S. Naval Sea Systems Command. Nuclear powered submarine atmosphere control manual. NAVSEA S9510-AB-ATM-010/(U). Vol. 1, rev. 2. 30 July 1992.

Table 1 Precision Testing

R.S.D. = Relative Standard Deviation

(n = 5 in all cases)

8% CO2

		Week 1 Calibrated	Week 2 Calibrated	Week 3 Calibrated	Week 4 Calibrated
Enmet	Mean	9.5	8.0	7.8	7.7
	R.S.D. (%)	**0**	**0.69**	**2.64**	**1.75**
	Range	-	7.9 - 8.0	7.5 - 8.0	7.6 - 7.9
RKI	Mean	8.100	7.970	8.070	8.060
	R.S.D. (%)	**0.00**	**0.56**	**0.83**	**0.28**
	Range	-	7.950 - 8.050	7.950 - 8.100	8.050 - 8.100
Nova	Mean	8.1	8.1	8.0	8.1
	R.S.D. (%)	**1.03**	**1.03**	**0.00**	**0.00**
	Range	8.0 - 8.2	8.0 - 8.2	-	-
GeoL	Mean	8.104	8.140	8.088	7.970
	R.S.D. (%)	**0.40**	**0.39**	**0.67**	**0.50**
	Range	8.080 - 8.160	8.100 - 8.180	8.020 - 8.170	7.920 - 8.020
GeoS	Mean	8.004	8.152	8.110	7.900
	R.S.D. (%)	**0.23**	**0.54**	**0.29**	**0.39**
	Range	7.980 - 8.030	8.110 - 8.220	8.080 - 8.130	7.870 - 7.950

5% CO2

		Week 1 Calibrated	Week 2 Calibrated	Week 3 Calibrated	Week 4 Calibrated
Enmet	Mean	4.9	5.0	5.1	5.0
	R.S.D. (%)	**0.91**	**0.90**	**0.88**	**0.00**
	Range	4.9 - 5.0	4.9 - 5.0	5.0 - 5.1	-
RKI	Mean	5.036	5.100	5.010	5.090
	R.S.D. (%)	**0.33**	**0.00**	**0.83**	**0.44**
	Range	5.010 - 5.050	-	4.950 - 5.050	5.050 - 5.100
Nova	Mean	5.0	5.0	5.1	5.0
	R.S.D. (%)	**0.00**	**0.00**	**0.88**	**0.00**
	Range	*	-	5.0 - 5.1	-
GeoL	Mean	5.056	5.030	5.036	5.036
	R.S.D. (%)	**0.36**	**0.58**	**0.33**	**0.39**
	Range	5.030 - 5.080	5.010 - 5.080	5.010 - 5.050	5.010 - 5.050
GeoS	Mean	5.042	5.024	5.036	5.032
	R.S.D. (%)	**0.17**	**0.36**	**0.23**	**0.33**
	Range	5.030 - 5.050	5.000 - 5.050	5.020 - 5.050	5.010 - 5.050

2.5% CO2

		Week 1 Calibrated	Week 2 Calibrated	Week 3 Calibrated	Week 4 Calibrated
Enmet	Mean	-	-	2.4	2.5
	R.S.D. (%)	-	-	**5.10**	**0.00**
	Range	-	-	2.2 - 2.5	-
RKI	Mean	2.450	2.470	2.450	2.480
	R.S.D. (%)	**0.00**	**1.81**	**1.44**	**1.10**
	Range	-	2.400 - 2.500	2.400 - 2.500	2.450 - 2.500
Nova	Mean	-	-	2.5	2.5
	R.S.D. (%)	-	-	**2.16**	**0.00**
	Range	-	-	2.5 - 2.6	-
GeoL	Mean	2.472	2.482	2.480	2.480
	R.S.D. (%)	**0.34**	**0.34**	**0.49**	**0.81**
	Range	2.460 - 2.480	2.47-2.49	2.470 - 2.500	2.450 - 2.500
GeoS	Mean	2.490	2.482	2.482	2.486
	R.S.D. (%)	**0.00**	**0.18**	**0.72**	**0.22**
	Range	-	2.480 - 2.490	2.450 - 2.490	2.480 - 2.490

0.25% CO2

		Week 1 Calibrated	Week 2 Calibrated	Week 3 Calibrated	Week 4 Calibrated
Enmet	Mean	-	-	-	-
	R.S.D. (%)	-	-	-	-
	Range	-	-	-	-
RKI	Mean	0.300	0.300	0.300	0.300
	R.S.D. (%)	**0.00**	**0.00**	**0.00**	**0.00**
	Range	-	-	-	-
Nova	Mean	-	-	-	-
	R.S.D. (%)	-	-	-	-
	Range	-	-	-	-
GeoL	Mean	-	-	0.255	0.255
	R.S.D. (%)	-	-	**0.75**	**0.70**
	Range	-	-	0.253 - 0.258	0.252 - 0.256
GeoS	Mean	-	-	0.254	0.259
	R.S.D. (%)	-	-	**0.99**	**0.50**
	Range	-	-	0.252-0.258	0.257 - 0.260

Table 2A Enmet Short-term and Long-term Testing

Relative Percent Error

10.1% CO2

		Short Term Test				Long Term Test												
Stec	Expected	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		01/09/95	01/18/95	01/27/95	02/03/95	02/10/95	02/15/95	02/24/95	03/02/95	03/08/95	03/16/95	03/20/95	03/30/95	04/05/95	04/12/95	04/20/95		
0	0.0	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated											-	-
10	1.0	-10	**-20**	**-20**	-10	-10	10	0	10	10	0	0	0	**40**	**80**	**60**	-	-
20	2.0	-10	**-15**	-10	-5	-10	5	0	5	5	0	0	0	**30**	**55**	**40**	-	-
30	3.0	-7	**-13**	-7	-7	-7	3	0	3	3	0	0	0	20	**47**	**33**	-	-
40	4.0	-6	**-13**	-10	-5	-5	2	2	5	0	0	0	0	23	**43**	**30**	-	-
50	5.1	-7	**-12**	**-12**	-6	-6	2	2	4	-2	-2	-2	0	18	**39**	**27**	-	-
60	6.1	-6	-10	-10	-3	-3	7	5	7	5	0	-2	0	21	**39**	**30**	-	-
70	7.1	-1	-8	-7	-1	-1	6	6	10	3	6	1	6	20	**34**	**27**	-	-
80	8.1	-1	-7	-4	-1	-1	5	10	11	4	5	5	6	17	23	23	-	-
70	7.1	-3	-8	-3	-1	-1	6	6	7	6	3	0	6	20	**34**	**27**	-	-
60	6.1	-6	-10	-10	-3	-3	5	-2	5	-2	-2	-2	0	16	**34**	**28**	-	-
50	5.1	-7	**-12**	-10	-6	-6	0	0	2	-2	-2	-2	-2	18	**37**	**27**	-	-
40	4.0	-6	**-13**	-10	-7	-7	2	0	2	0	0	-5	0	20	**38**	**30**	-	-
30	3.0	-7	**-13**	-7	-3	-7	3	0	3	0	0	-3	0	20	**43**	**33**	-	-
20	2.0	-10	**-20**	-5	-5	-10	5	0	5	10	0	-5	0	**30**	**55**	**45**	-	-
10	1.0	-5	**-20**	0	0	-10	10	0	10	0	0	0	0	**40**	**80**	**60**	-	-
0	0.0																	

5.04% CO2

		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Stec	Expected	01/09/95	01/18/95	01/26/95	02/03/95	02/10/95	02/15/95	02/24/95	03/02/95	03/08/95	03/15/95	03/20/95	03/31/95	04/05/95	04/12/95	04/20/95		
0	0.0	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated											-	-
10	0.5	**-21**	**-21**	**-11**	1	-21	-21	1	1	1	1	1	-21	**59**	**59**	**79**	-	-
20	1.0	**-11**	**-21**	1	1	-11	1	1	1	9	1	1	1	**39**	**39**	**59**	-	-
30	1.5	-7	**-14**	-7	-7	-7	-7	6	6	-7	1	-7	-7	**32**	**32**	**46**	-	-
40	2.0	**-11**	**-11**	-6	-6	-11	1	4	1	1	1	1	1	**29**	**29**	**39**	-	-
50	2.5	-5	**-13**	-5	-5	-5	1	3	3	3	1	1	-5	23	23	**35**	-	-
60	3.0	-7	-7	-4	1	-7	1	3	3	1	1	1	1	19	**26**	**32**	-	-
70	3.5	-8	-9	-4	-4	-6	1	5	2	1	1	1	1	19	25	**30**	-	-
80	4.0	-7	**-11**	-3	-3	-3	1	4	1	4	1	1	1	22	24	**34**	-	-
90	4.5	-6	-10	-3	-3	-5	1	6	4	1	1	1	1	21	23	**32**	-	-
100	5.0	-6	-9	1	1	-3	1	7	9	1	1	1	1	21	27	**31**	-	-
90	4.5	-6	-10	-3	-3	-5	1	4	1	1	1	1	1	21	23	**32**	-	-
80	4.0	-7	**-11**	-3	-3	-18	1	2	1	1	1	1	1	22	24	**31**	-	-
70	3.5	-8	-9	-6	-4	-18	1	2	2	2	1	1	1	19	22	**30**	-	-
60	3.0	-4	-7	-4	1	-21	1	3	6	1	1	1	1	19	19	**32**	-	-
50	2.5	-5	-9	-5	-5	-17	1	3	3	3	-5	-5	1	23	23	**35**	-	-
40	2.0	-6	**-11**	1	1	-21	1	1	4	1	1	1	1	**29**	**29**	**39**	-	-
30	1.5	-7	-7	-7	1	-21	-7	6	6	6	-7	-7	-7	**32**	**32**	**46**	-	-
20	1.0	**-11**	**-21**	1	1	-21	1	9	1	1	1	1	1	**39**	**39**	**59**	-	-
10	0.5	**-21**	**-21**	1	1	**-40**	-21	1	1	1	-21	-21	-21	**39**	**79**	**98**	-	-
0	0.0																	

Note: Bold Values Exceed Test Reqiurements

Table 2A (cont.)

Enmet

Relative Percent Error

2.48% CO2

		Short Term Test				Long Term Test												
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Stec	**Expected**	01/09/95	01/18/95	01/27/95	02/03/95	02/09/95	02/16/95	02/24/95	03/02/95	03/08/95	03/15/95	03/20/95	03/30/95	04/06/95	04/13/95	04/20/95	-	-
0	0.00			Calibrated	Calibrated	Calibrated											-	-
10	0.25	-	-	16	-20	-20	-20	20	0	60	20	-20	20	100	100	220	-	-
20	0.50	-	-	-20	-20	-20	-20	0	0	40	0	-20	0	60	60	140	-	-
30	0.75	-	-	0	-7	-33	-7	7	-7	20	-20	-7	7	33	47	87	-	-
40	1.00	-	-	0	-10	-20	-10	0	0	20	0	0	0	40	40	80	-	-
50	1.25	-	-	-12	-4	-20	-12	12	-4	28	4	-4	-4	28	44	60	-	-
60	1.50	-	-	0	-7	-13	-7	7	7	13	7	-7	0	33	33	60	-	-
70	1.75	-	-	-9	-9	-14	-3	3	3	14	3	-3	3	26	31	60	-	-
80	2.00	-	-	0	-5	-10	0	5	5	10	0	0	0	30	30	50	-	-
90	2.25	-	-	2	-7	-11	-2	7	7	16	2	-2	7	24	33	51	-	-
100	2.50	-	-	-4	-4	-8	0	8	4	20	4	0	4	24	28	44	-	-
90	2.25	-	-	-7	-7	-11	-2	7	7	11	2	-2	7	24	33	51	-	-
80	2.00	-	-	0	-5	-10	0	5	0	10	0	0	0	30	30	50	-	-
70	1.75	-	-	-3	-9	-9	-3	9	3	3	3	-3	3	26	31	60	-	-
60	1.50	-	-	-7	-7	-7	-7	7	0	7	0	0	0	33	33	60	-	-
50	1.25	-	-	-20	-4	-20	-4	4	-4	4	4	-4	-4	28	44	60	-	-
40	1.00	-	-	-10	0	-20	-10	10	0	0	0	0	0	40	40	70	-	-
30	0.75	-	-	-7	-7	-33	-20	7	7	20	-7	-7	-7	33	47	87	-	-
20	0.50	-	-	-20	-20	-20	-20	0	0	0	0	-20	0	40	60	100	-	-
10	0.25	-	-	-20	-20	-60	20	20	0	0	20	-20	-20	60	100	180	-	-
0	0.00																	

Table 2B RKI Short-term and Long-term Testing

Relative Percent Error

10.1% CO2

Stec	Expected	Short Term Test				Long Term Test												
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/06/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/19/95	05/24/95	05/30/95	06/06/95	06/14/95	06/22/95
0	0.0	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated												
10	1.0	4	4	1	1	4	4	9	4	4	9	14	24	24	**29**	24	24	29
20	2.0	4	1	1	1	1	1	6	4	1	6	6	14	14	19	19	14	21
30	3.0	6	1	1	1	1	1	6	2	1	6	6	12	12	17	14	12	19
40	4.0	6	3	-2	1	1	0	6	3	3	8	5	10	10	15	13	11	16
50	5.1	6	1	-3	-2	1	0	4	2	1	6	4	9	9	13	11	10	14
60	6.1	4	1	-3	1	1	0	4	1	1	5	2	6	6	11	9	8	12
70	7.1	5	0	-3	-2	0	0	3	0	0	5	3	6	6	10	8	7	12
80	8.1	5	0	-3	-2	0	-2	2	0	0	3	2	6	6	10	8	7	10
70	7.1	5	0	-4	-2	0	-2	3	0	0	5	3	6	6	10	8	7	10
60	6.1	5	1	-4	0	0	1	4	1	1	5	2	6	6	11	9	8	12
50	5.1	6	1	-3	0	0	1	4	1	1	6	4	9	9	13	11	10	14
40	4.0	6	3	-2	0	1	1	6	3	3	6	5	10	10	15	13	11	16
30	3.0	6	1	-4	1	1	1	6	2	1	6	6	12	12	17	14	12	19
20	2.0	4	1	-6	1	1	1	6	4	1	6	6	14	14	19	19	14	21
10	1.0	4	4	1	4	4	1	14	4	4	9	14	24	19	**29**	24	24	29
0	0.0																	

5.04% CO2

Stec	Expected	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/06/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/19/95	05/24/95	05/30/95	06/06/95	06/14/95	06/22/95
0	0.0	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated												
10	0.5	9	**19**	**19**	**19**	19	9	9	19	19	**29**	**29**	**49**	**50**	**60**	**60**	**50**	**60**
20	1.0	1	4	4	4	4	4	4	4	4	14	14	24	25	**30**	25	25	**35**
30	1.5	1	1	1	1	1	1	1	3	3	9	9	19	17	23	20	17	**27**
40	2.0	1	2	1	2	2	1	1	4	2	9	9	14	15	20	20	15	25
50	2.5	1	1	1	1	1	1	1	3	3	7	7	15	14	20	16	16	22
60	3.0	1	1	1	1	1	1	2	4	3	7	7	12	13	18	15	13	22
70	3.5	1	3	-2	2	3	2	2	3	3	8	8	12	13	17	13	13	19
80	4.0	0	3	-2	2	3	2	2	4	3	8	7	12	11	16	14	13	18
90	4.5	0	1	-2	1	1	1	1	4	3	7	6	10	10	14	13	11	16
100	5.0	0	1	-2	1	2	1	1	3	2	7	6	10	11	15	13	11	15
90	4.5	0	1	-2	1	1	1	1	4	4	7	6	10	10	16	13	11	16
80	4.0	0	2	-2	2	2	2	2	4	3	8	7	10	11	16	14	13	18
70	3.5	1	2	-2	2	3	1	2	3	3	8	8	12	13	17	14	13	19
60	3.0	1	1	-4	1	1	1	1	4	3	7	7	12	13	18	15	13	20
50	2.5	1	1	-5	1	1	1	1	5	1	7	7	15	14	20	16	16	22
40	2.0	1	1	-6	1	2	1	2	4	2	7	9	14	15	20	20	15	25
30	1.5	1	1	-4	1	1	1	1	3	3	9	9	19	17	23	20	17	**27**
20	1.0	4	1	-6	1	4	1	4	9	4	14	14	24	25	30	25	25	**35**
10	0.5	9	9	9	9	19	9	19	19	19	**29**	**29**	**49**	**50**	**60**	**60**	**50**	**60**
0	0.0																	

Note: Bold Values Exceed Test Reqiurements

Table 2B (cont.)

RKI

Relative Percent Error

2.48% CO2

		Short Term Test				Long Term Test												
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Stec	Expected	02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/06/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/19/95	05/24/95	05/30/95	06/06/95	06/14/95	06/22/95
0	0.00	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated												
10	0.25	41	41	41	41	41	41	41	61	41	61	81	122	101	121	121	101	81
20	0.50	11	15	11	11	21	21	21	31	21	31	41	61	51	71	61	51	41
30	0.75	8	1	8	1	8	8	8	21	8	21	28	34	34	41	41	34	20
40	1.00	1	1	1	-9	6	6	6	16	6	16	21	26	26	36	31	26	15
50	1.25	1	-3	-3	-11	1	1	1	9	1	9	17	21	20	29	24	20	12
60	1.50	-3	-3	-3	-13	1	1	1	8	1	8	14	21	20	27	20	17	14
70	1.75	-2	-2	-5	-11	1	1	4	7	1	9	12	21	18	26	20	18	9
80	2.00	-4	-4	-4	-9	1	3	3	8	3	8	13	16	15	26	18	15	10
90	2.25	-4	-1	-4	-8	3	3	3	8	3	8	12	19	16	23	18	14	12
100	2.50	-3	-1	-3	-7	1	3	3	9	1	9	11	17	16	22	18	16	10
90	2.25	-1	-4	-4	-10	1	3	3	8	3	8	12	19	16	23	18	16	12
80	2.00	1	-4	-4	-12	1	1	3	8	3	8	13	16	15	26	20	15	10
70	1.75	-2	-5	-5	-16	1	1	4	7	4	7	9	21	18	26	20	18	9
60	1.50	-3	-6	-6	-16	1	1	1	8	1	8	14	21	17	27	20	17	10
50	1.25	1	-7	-3	-19	1	1	1	9	1	9	17	21	20	29	24	20	12
40	1.00	1	-9	-4	-24	1	6	6	11	6	16	16	26	26	36	26	26	15
30	0.75	8	-6	1	-26	8	8	8	21	8	21	21	34	34	41	41	34	20
20	0.50	11	1	11	-29	11	11	21	31	21	31	41	51	51	71	61	51	41
10	0.25	41	1	21	-100	41	41	41	61	41	61	81	102	101	121	121	101	81
0	0.00																	

0.26% CO2

		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Stec	Expected	02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/06/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/19/95	05/24/95	05/30/95	06/06/95	06/14/95	06/22/95
0	0.000	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated												
10	0.025	-100	92	-100	92	477	92	477	477	92	477	669	1246	1246	1246	1054	669	862
20	0.050	-4	92	-4	92	188	92	188	285	92	285	381	573	573	573	477	381	477
30	0.075	28	28	28	28	156	28	156	221	92	221	285	413	413	413	349	285	285
40	0.100	-4	44	-4	44	92	92	140	188	44	188	237	285	285	285	285	188	237
50	0.125	15	15	15	54	92	54	92	131	54	131	169	246	246	246	208	169	169
60	0.150	28	28	-4	28	60	60	92	124	60	124	156	221	221	221	188	156	156
70	0.175	10	10	10	10	65	65	92	92	37	92	120	175	175	175	147	120	120
80	0.200	-4	20	-4	20	44	68	68	92	44	92	116	164	140	164	140	116	116
90	0.225	7	28	7	7	50	50	71	71	50	71	114	135	135	135	114	92	114
100	0.250	-4	15	-4	15	35	54	54	73	35	73	92	112	112	112	112	92	92
90	0.225	7	28	-15	28	50	71	71	71	50	71	114	135	135	135	114	92	114
80	0.200	-4	20	-4	20	44	68	68	92	44	92	116	140	140	164	140	116	116
70	0.175	10	37	10	37	37	92	92	92	37	92	120	175	175	175	147	120	120
60	0.150	-4	28	-4	28	28	124	92	124	60	124	156	188	188	221	188	156	156
50	0.125	15	54	-23	54	54	131	131	131	54	131	169	208	208	246	208	169	169
40	0.100	-4	44	-4	44	44	188	140	188	92	188	188	285	285	285	285	188	237
30	0.075	28	92	-36	92	28	221	233	221	92	221	285	349	349	349	349	285	285
20	0.050	-4	92	-100	92	-4	285	188	285	92	285	381	573	477	573	477	381	381
10	0.025	-100	92	-100	92	-100	477	477	477	92	477	669	1054	862	1054	1054	669	669
0	0.000																	

Table 2C Nova Short-term and Long-term Testing

Relative Percent Error

10.1% CO2

Stec	Expected	Short Term Test				Long Term Test												
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		01/09/95	01/18/95	01/27/95	02/03/95	02/10/95	02/15/95	02/24/95	03/02/95	03/08/95	03/16/95	03/20/95	03/30/95	04/05/95	04/12/95	04/20/95	04/28/95	05/04/95
		Calibrated	Calibrated	Calibrated	Calibrated	Calibrated												
0	0.0																	
10	1.0	0	10	0	0	0	10	0	0	-10	0	0	0	0	-10	0	-10	-10
20	2.0	-5	-5	-10	-5	-5	-10	-15	-10	-15	-10	-10	-15	-10	-20	-15	-15	-20
30	3.0	-3	-7	-10	-10	-10	-10	-13	-10	-17	-10	-10	-13	-10	-20	-13	-17	-20
40	4.0	0	-3	-5	-5	-5	-5	-10	-7	-15	-7	-5	-10	-7	-18	-7	-13	-18
50	5.1	0	-2	-4	-4	-4	-2	-10	-8	-16	-6	-4	-10	-4	-16	-8	-12	-16
60	6.1	2	0	-3	-2	-2	-2	-7	-5	-11	-3	-2	-7	-3	-13	-5	-10	-11
70	7.1	3	0	-1	0	-1	1	-6	-4	-11	-1	0	-4	0	-11	-3	-8	-10
80	8.1	2	0	-1	-1	-1	0	-5	-5	-11	-1	0	-4	0	-11	-4	-7	-10
70	7.1	3	0	0	0	-1	1	-6	-10	-11	-3	1	-4	0	-11	-3	-8	-10
60	6.1	2	0	-2	-2	-2	0	-7	-5	-13	-3	0	-7	-2	-13	-5	-10	-11
50	5.1	0	-2	-4	-4	-4	-4	-10	-8	-14	-6	-4	-10	-4	-16	-8	-14	-14
40	4.0	0	-3	-7	-5	-5	-5	-10	-7	-18	-7	-5	-10	-7	-18	-7	-15	-15
30	3.0	-3	-3	-10	-7	-10	-7	-13	-10	-20	-10	-10	-13	-10	-20	-13	-17	-20
20	2.0	-5	-5	-10	-10	-10	-5	-15	-10	-20	-10	-10	-10	-10	-20	-15	-15	-20
10	1.0	10	10	0	0	0	10	0	0	-10	0	0	0	0	-10	0	-10	-10
0	0.0																	

5.04% CO2

Stec	Expected	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		01/09/95	01/18/95	01/26/95	02/03/95	02/10/95	02/15/95	02/24/95	03/02/95	03/08/95	03/15/95	03/20/95	03/31/95	04/05/95	04/12/95	04/20/95	04/28/95	05/04/95
0	0.0	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated												
10	0.5	1	**19**	**19**	1	1	1	1	1	1	1	1	1	-21	1	1	-21	-21
20	1.0	1	9	9	1	1	1	1	1	1	1	1	1	1	1	-11	-11	-11
30	1.5	1	1	1	1	-7	1	-14	-7	-7	-7	-7	-14	-7	-7	-7	-14	-21
40	2.0	-6	-6	-6	-6	-11	-11	-16	-11	-16	-11	-11	-16	-16	-11	-16	-16	-16
50	2.5	-9	-5	-9	-9	-13	-9	-13	-13	-17	-13	-13	-13	-17	-13	-17	-21	-21
60	3.0	-7	-7	-7	-7	-11	-7	-14	-14	-17	-11	-14	-14	-14	-11	-14	-17	-21
70	3.5	-4	-6	-4	-4	-9	-6	-12	-9	-15	-9	-12	-12	-12	-9	-12	-18	-18
80	4.0	-3	-3	1	-3	-8	-3	-11	-11	-13	-8	-8	-8	-11	-8	-11	-13	-16
90	4.5	1	1	1	1	-5	-3	-10	-7	-12	-5	-7	-7	-10	-5	-7	-12	-14
100	5.0	1	1	1	1	-3	1	-9	-5	-11	-3	-5	-5	-9	-3	-5	-11	-13
90	4.5	1	1	1	1	-5	1	-10	-10	-10	-5	-7	-10	-10	-3	-7	-12	-16
80	4.0	-3	-3	1	-3	-8	-6	-11	-11	-13	-6	-8	-11	-11	-8	-11	-13	-18
70	3.5	-4	-6	-4	-4	-9	-6	-12	-9	-15	-9	-9	-12	-12	-9	-12	-15	-18
60	3.0	-7	-7	-4	-7	-11	-7	-14	-11	-17	-11	-14	-14	-14	-11	-14	-17	-21
50	2.5	-9	-9	-5	-9	-13	-9	-17	-13	-17	-13	-13	-13	-17	-13	-17	-17	-21
40	2.0	-6	-6	-6	-6	-6	-11	-16	-11	-16	-11	-11	-16	-11	-11	-11	-16	-21
30	1.5	1	1	1	1	-7	-7	-7	-7	-14	-7	-7	-14	-7	-7	-14	-14	-14
20	1.0	9	9	9	1	1	9	1	1	1	1	1	1	1	1	1	-11	-11
10	0.5	1	**19**	**19**	1	1	1	1	1	1	1	1	1	1	1	1	-21	-21
0	0.0																	

Note: Bold Values Exceed Test Reqiurements

Table 2C (cont.)

Nova

Relative Percent Error

2.48% CO2

		Short Term Test				Long Term Test												
Stec	Expected	Week 1 01/09/95	Week 2 01/18/95	Week 3 01/27/95 Calibrated	Week 4 02/03/95 Calibrated	Week 1 02/09/95 Calibrated	Week 2 02/16/95	Week 3 02/24/95	Week 4 03/02/95	Week 5 03/08/95	Week 6 03/15/95	Week 7 03/20/95	Week 8 03/30/95	Week 9 04/06/95	Week 10 04/13/95	Week 11 04/20/95	Week 12 04/28/95	Week 13 05/04/95
0	0.0																	
10	0.3	-	-	20	20	-20	-20	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60
20	0.5	-	-	40	40	0	0	0	0	0	0	0	0	0	-20	-20	-20	-20
30	0.8	-	-	33	33	7	7	-7	7	7	7	-7	-7	-7	-7	-7	-20	-7
40	1.0	-	-	20	20	0	0	0	0	0	0	-10	0	0	0	0	-10	-10
50	1.3	-	-	12	12	-4	-4	-12	-12	-12	-12	-12	-12	-12	-4	-12	-12	-12
60	1.5	-	-	7	7	-7	-7	-7	-13	-13	-7	-13	-7	-13	-7	-13	-13	-20
70	1.8	-	-	3	3	-9	-9	-14	-14	-14	-14	-14	-14	-14	-14	-14	-20	-20
80	2.0	-	-	5	0	-10	-10	-15	-15	-20	-15	-15	-15	-15	-15	-15	-20	-20
90	2.3	-	-	2	2	-11	-11	-16	-16	-16	-16	-16	-16	-16	-11	-16	-16	-20
100	2.5	-	-	4	0	-12	-12	-16	-12	-16	-16	-16	-16	-16	-12	-16	-20	-20
90	2.3	-	-	2	2	-11	-11	-16	-16	-16	-16	-16	-16	-16	-11	-16	-20	-20
80	2.0	-	-	5	0	-10	-10	-15	-15	-15	-15	-15	-15	-15	-15	-15	-20	-20
70	1.8	-	-	3	3	-9	-9	-14	-14	-14	-14	-14	-14	-14	-14	-14	-20	-14
60	1.5	-	-	7	-33	-7	-7	-7	-7	-13	-7	-13	-7	-13	-7	-13	-13	-20
50	1.3	-	-	12	12	-4	-4	-12	-4	-4	-4	-4	-12	-12	-4	-12	-12	-12
40	1.0	-	-	20	20	0	0	-10	0	0	0	0	0	0	0	-10	-10	-20
30	0.8	-	-	33	33	7	7	-7	7	-7	-7	-7	-7	-7	-7	-7	-20	-20
20	0.5	-	-	40	40	0	0	0	0	0	0	0	0	0	0	-20	-20	-20
10	0.3	-	-	60	60	-20	-20	-60	-60	-60	-60	-60	-60	-60	-60	-60	-20	-60
0	0.0																	

Table 2D GeoL Short-term and Long-term Testing

Relative Percent Error

10.1% CO2

Stec	Expected	Short Term Test				Long Term Test												
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		02/10/95	02/16/95	02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/05/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/16/95	05/24/95	05/30/95	06/06/95
0	0.0	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated						Calibrated						
10	1.0	-3	-2	-3	-3	-3	-5	-2	-3	-2	-3	-2	-1	-1	-2	0	1	0
20	2.0	-2	0	1	-1	1	-2	1	1	1	-2	0	0	0	0	1	1	1
30	3.0	-4	-2	-2	-3	-3	-4	-3	-3	-3	-3	-2	-2	-2	-2	1	0	1
40	4.0	-3	-2	-2	-3	-3	-4	-3	-3	-3	-2	-1	1	1	1	1	1	1
50	5.1	-3	0	-3	-2	-3	-4	-3	-3	-4	-2	0	1	-1	0	1	1	-1
60	6.1	-3	1	-3	-2	-2	-3	-2	-2	-3	-3	-1	1	1	0	2	0	0
70	7.1	-2	0	-1	-3	1	-2	-2	0	-3	1	1	1	1	1	5	1	0
80	8.1	1	1	0	-2	-1	0	-2	1	-3	-1	2	0	1	1	6	2	0
70	7.1	-1	1	-3	-2	-3	1	-3	-2	-4	-2	1	0	0	1	6	1	0
60	6.1	-3	0	-3	-1	-3	-3	-3	-2	-4	-3	1	1	-1	0	3	1	-2
50	5.1	-3	-2	-3	-3	-3	-3	-3	-2	-4	-4	-3	-1	-1	-1	2	-1	-1
40	4.0	-3	-2	-3	-3	-3	-4	-4	-3	-4	-3	-1	-2	-2	1	1	0	1
30	3.0	-4	-3	-3	-3	-4	-4	-4	-3	-4	-3	-2	1	-2	-2	0	-1	0
20	2.0	-2	-1	1	-1	-2	-4	-2	-2	-2	-3	1	0	0	1	1	1	1
10	1.0	-5	-3	-3	-3	2	-6	-3	-4	-3	-4	-2	-1	-2	-2	0	0	1
0	0.0																	

5.04% CO2

Stec	Expected	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		02/10/95	02/16/95	02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/05/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/16/95	05/24/95	05/30/95	06/06/95
0	0.0	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated						Calibrated						
10	0.5	-3	-3	-6	-3	-4	-6	-6	-7	-9	-6	-5	-2	-3	-4	-1	1	-2
20	1.0	0	-1	-1	1	-2	-2	-2	-2	-3	-2	1	1	0	0	2	3	1
30	1.5	1	0	0	0	-1	-2	-1	-2	-3	-1	1	1	1	1	1	3	1
40	2.0	1	0	0	0	1	-1	1	-1	-2	-1	1	2	1	1	2	3	1
50	2.5	-1	1	-1	-1	-2	-2	-2	-2	-2	-2	0	2	0	0	1	2	1
60	3.0	-2	-1	-2	-2	-2	-3	-3	-3	-3	-3	-1	1	1	0	1	1	0
70	3.5	-1	-1	-1	1	-2	-3	-2	-3	-2	-2	-2	-1	-1	0	1	1	1
80	4.0	1	-1	-2	-2	-2	-4	-3	-3	-2	-3	1	-1	-1	0	1	1	0
90	4.5	-1	-1	-1	-1	-3	-3	-3	-3	-3	-3	-1	-1	-1	1	2	0	1
100	5.0	0	0	1	1	-1	-1	-3	-2	1	-2	1	1	1	1	3	0	0
90	4.5	-1	-1	-2	-2	-3	-3	-3	-4	-2	-3	1	-1	-1	1	2	1	0
80	4.0	-1	1	-2	-1	-2	-3	-3	-3	-3	-3	1	0	1	0	1	0	1
70	3.5	-1	-2	-2	-2	-3	-3	-3	-4	-3	-2	1	-1	1	1	1	0	0
60	3.0	-2	-1	-3	-2	-3	-4	-3	-3	-3	-3	-2	-1	-2	-1	1	1	1
50	2.5	-2	0	-2	0	-2	-3	-3	-3	1	-3	1	0	-1	0	2	2	0
40	2.0	-1	0	-1	0	-2	-2	-2	-2	-2	-2	0	1	0	4	2	2	1
30	1.5	-2	0	-1	-1	-3	-3	-3	-3	-3	-3	1	0	1	-1	1	3	1
20	1.0	1	-1	-2	-2	0	-2	-3	-4	-4	-2	-1	1	1	1	1	2	0
10	0.5	-5	-4	-2	6	-7	-9	**32**	-9	-10	-8	-6	-3	-5	-5	-8	0	-2
0	0.0																	

Note: Bold Values Exceed Test Requirements

Table 2D (cont.)

GeoL

Relative Percent Error

2.48% CO2

		Short Term Test				Long Term Test												
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Stec	Expected	02/10/95	02/16/95	02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/05/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/16/95	05/24/95	05/30/95	06/06/95
0	0.00	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated						Calibrated						
10	0.3	-2	-3	-6	-4	-11	-9	-7	-9	-13	-8	-9	-5	-6	-6	-4	-2	-6
20	0.5	-1	-1	-3	-2	-7	-5	-4	-5	-6	-4	-4	-1	-3	-3	-2	2	-2
30	0.8	-2	-2	-4	-2	-6	-5	-4	-5	-7	-3	-4	-1	-3	-6	0	1	-2
40	1.0	1	1	-1	0	-4	-2	-1	-2	-3	1	1	1	0	0	1	2	0
50	1.3	0	0	-2	0	-2	-2	0	1	-2	0	0	2	2	2	3	4	2
60	1.5	-1	1	-3	1	-3	-3	-1	-3	-3	-1	-1	0	1	0	2	2	0
70	1.8	0	0	-2	0	-3	-1	1	1	-1	0	0	1	1	1	3	3	2
80	2.0	0	0	-1	0	-4	-2	-2	-2	-2	-1	0	1	0	1	2	3	0
90	2.3	1	1	1	0	-5	-1	-1	1	-1	1	0	1	0	1	2	2	1
100	2.5	1	1	1	1	-3	-2	-2	-2	-2	-2	0	0	0	0	2	2	0
90	2.3	1	1	-1	0	-2	-1	-1	-1	-1	1	1	1	0	0	3	3	0
80	2.0	1	-1	-2	1	-3	-2	-1	-2	-2	0	1	1	0	1	2	2	1
70	1.8	0	1	-2	0	-3	1	1	-1	-1	0	0	1	1	1	2	2	2
60	1.5	-2	-1	-3	-1	-3	-3	-2	-3	0	-2	1	0	1	1	2	2	0
50	1.3	1	1	-4	0	-4	-2	1	-2	-2	2	0	2	0	0	2	4	2
40	1.0	-2	-1	-5	1	-4	-3	-2	-3	-3	-2	-2	0	0	1	1	1	0
30	0.8	-4	-4	-8	-4	-7	-6	-5	-6	-7	-4	-5	-3	-4	-3	-1	1	-3
20	0.50	-4	-3	-9	-4	-9	-6	-6	-7	-8	-5	-4	-3	-3	-4	-2	1	-2
10	0.25	-7	-6	-22	-8	-13	-9	-9	-11	-14	-10	-9	-6	-7	-8	-7	-2	-6
0	0.00																	

0.26% CO2

		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Stec	Expected	02/10/95	02/16/95	02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/05/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/16/95	05/24/95	05/30/95	06/06/95
0	0.000			Calibrated	Calibrated	Calibrated						Calibrated						
10	0.025	-	-	-54	-46	-38	-65	-69	-65	-62	*	-77	-58	-50	-46	-35	-35	-58
20	0.050	-	-	-19	-13	-15	-25	-29	-27	-25	*	-29	-21	-19	-17	-13	-12	-19
30	0.075	-	-	-13	-10	-13	-22	-21	-19	-18	*	-22	-14	-14	-13	-9	-9	-14
40	0.100	-	-	-13	-12	-14	-20	-20	-19	-18	*	-20	-12	-15	-14	-12	-10	-13
50	0.125	-	-	-18	-15	-18	-22	-22	-22	-21	*	-22	-17	-17	-16	-15	-14	-17
60	0.150	-	-	-19	-19	-21	-24	-24	-24	-22	*	-23	-21	-20	-19	-19	-17	-19
70	0.175	-	-	-22	-22	-23	-26	-26	-26	-25	*	-26	-23	-21	-22	-22	-10	-24
80	0.200	-	-	-10	-8	-12	-17	-20	-18	-16	*	-18	-10	-11	-12	-8	-7	-11
90	0.225	-	-	-6	-6	-9	-15	-15	-15	-13	*	-13	-8	-7	-8	-6	-4	-8
100	0.250	-	-	-4	-4	-8	-12	-12	-11	-10	*	-10	-5	-6	-7	-4	-2	-7
90	0.225	-	-	-7	-5	-10	-14	-14	-13	-12	*	-12	-6	-9	-9	-7	-6	-9
80	0.200	-	-	-13	-10	-13	-18	-20	-19	-17	*	-17	-12	-12	-12	-10	-8	-12
70	0.175	-	-	-23	-23	-24	-26	-27	-26	-25	*	-26	-23	-23	-23	-21	-12	-23
60	0.150	-	-	-21	-20	-22	-24	-24	-24	-22	*	-24	-21	-21	-20	-19	-17	-21
50	0.125	-	-	-18	-16	12	-22	-23	-22	-21	*	-21	-17	-17	-15	-15	-15	-18
40	0.100	-	-	-16	-13	-16	-20	-22	-19	-19	*	-22	-15	-15	-12	-13	-11	-15
30	0.075	-	-	-17	-14	-17	-23	-19	-21	-21	*	-23	-14	-17	-14	-13	-10	-14
20	0.050	-	-	-23	-17	-19	-29	-29	-29	-27	*	-35	-15	-21	-15	-13	-13	-21
10	0.025	-	-	-69	-50	-50	-65	-73	-69	-69	*	-81	-54	-50	-46	-46	-38	-62
0	0.000																	

* User Error - Data and calibration loss. Recalibrated prior to week 7

Table 2E GeoS Short-term and Long-term Testing

Relative Percent Error

10.1% CO2

		Short Term Test				Long Term Test												
Stec	Expected	Week 1 02/10/95 Calibrated	Week 2 02/16/95 Calibrated	Week 3 02/27/95 Calibrated	Week 4 03/08/95 Calibrated	Week 1 03/15/95 Calibrated	Week 2 03/20/95	Week 3 03/30/95	Week 4 04/05/95	Week 5 04/13/95	Week 6 04/20/95	Week 7 04/28/95 Calibrated	Week 8 05/04/95	Week 9 05/11/95	Week 10 05/16/95	Week 11 05/24/95	Week 12 05/30/95	Week 13 06/06/95
0	0.0																	
10	1.0	-2	-2	-3	-5	-4	-6	-6	-4	-5	-5	-5	-4	-4	-4	-2	-2	-3
20	2.0	1	1	1	0	0	1	1	0	1	1	0	1	0	1	2	2	1
30	3.0	0	1	1	0	0	1	1	0	-1	1	0	1	1	1	2	2	1
40	4.0	1	0	0	1	-3	-2	-2	-2	-2	-1	1	1	0	0	1	0	0
50	5.1	-2	1	-1	-2	-2	-3	-3	-3	-5	-3	1	-1	-2	1	1	1	-1
60	6.1	-3	0	-1	-2	-2	-2	-3	-3	-5	-3	-1	0	1	-1	1	1	-1
70	7.1	-2	1	-1	-2	-2	-2	-3	-2	-5	-2	0	-2	0	0	3	0	-1
80	8.1	-1	1	1	1	1	1	-2	1	-5	1	1	0	0	1	4	1	0
70	7.1	-3	0	-2	-2	-2	-2	-3	-3	-6	-3	0	-1	1	1	3	1	-2
60	6.1	-3	1	-2	-2	-2	-3	-4	-3	-5	-3	-1	1	-1	-2	1	-1	-2
50	5.1	-2	-1	-1	-2	-2	-3	-4	-3	-5	-4	-2	1	-1	-1	1	-1	-1
40	4.0	-1	0	1	1	-2	-3	-2	-2	-3	-3	-1	1	1	0	1	0	0
30	3.0	0	0	0	0	1	-2	-2	1	-3	-1	0	1	0	0	2	0	0
20	2.0	0	1	0	0	0	-2	-1	1	-1	-1	1	0	0	0	2	1	1
10	1.0	-3	-3	-4	-4	1	-7	-6	-6	-6	-7	-5	-4	-5	-4	-2	-2	-3
0	0.0																	

5.04% CO2

Stec	Expected	Week 1 02/10/95 Calibrated	Week 2 02/16/95 Calibrated	Week 3 02/27/95 Calibrated	Week 4 03/08/95 Calibrated	Week 1 03/15/95 Calibrated	Week 2 03/20/95	Week 3 03/30/95	Week 4 04/05/95	Week 5 04/13/95	Week 6 04/20/95	Week 7 04/28/95 Calibrated	Week 8 05/04/95	Week 9 05/11/95	Week 10 05/16/95	Week 11 05/24/95	Week 12 05/30/95	Week 13 06/06/95
0	0.0																	
10	0.5	1	-2	-7	-7	-7	-9	-11	-11	-11	-10	-10	-9	-9	-8	-4	-6	-6
20	1.0	1	1	-3	-2	-2	-4	-5	-4	-5	-4	-4	-2	-3	-3	1	1	-2
30	1.5	2	1	1	1	1	-2	-3	-2	-3	-2	1	0	1	0	1	1	1
40	2.0	2	2	1	0	0	0	-1	1	1	0	1	2	1	1	3	2	2
50	2.5	2	2	1	0	0	0	-1	0	1	0	1	-1	1	2	3	2	2
60	3.0	2	2	1	1	0	0	1	0	1	0	1	2	1	2	3	2	1
70	3.5	1	1	1	0	0	1	-1	1	-1	1	0	0	1	1	3	2	0
80	4.0	0	0	1	1	-1	-1	-2	-2	-2	-2	0	0	0	0	2	1	1
90	4.5	0	0	1	1	1	-3	-2	-1	-1	-1	0	0	0	0	2	0	0
100	5.0	0	1	-1	-1	1	-1	-2	-2	-2	-2	0	0	1	0	2	1	0
90	4.5	0	0	1	-1	-1	-1	-2	-1	-2	-2	0	0	0	1	2	1	1
80	4.0	0	1	-1	-1	-1	-2	-2	-1	-2	-2	0	0	0	0	2	0	0
70	3.5	1	1	0	1	1	-1	-2	-2	-1	-1	0	0	1	1	3	1	1
60	3.0	1	2	0	0	0	1	-1	1	-1	1	0	2	0	1	2	2	1
50	2.5	1	2	0	0	0	1	-1	0	2	1	0	1	0	1	2	2	2
40	2.0	1	2	0	0	0	0	-1	-1	-1	1	0	1	0	3	2	2	2
30	1.5	1	1	-2	-2	-3	-3	-3	-3	-3	-3	-1	1	-1	1	1	1	1
20	1.0	1	1	-4	-4	-4	-5	-6	-5	-6	-5	-4	-4	-4	-3	1	-1	-2
10	0.5	-1	-4	-10	-4	-10	-9	18	-11	-12	-11	-11	-8	-9	-8	-7	-6	-6
0	0.0																	

Note: Bold Values Exceed Test Reqiurements

Table 2E (cont.)

GeoS

Relative Percent Error

2.48% CO2

		Short Term Test				Long Term Test												
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		02/10/95	02/16/95	02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/05/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/16/95	05/24/95	05/30/95	06/06/95
Stec	Expected	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated						Calibrated						
0	0.00																	
10	0.3	-10	-13	-19	-19	-22	-20	-21	-23	-22	-23	-23	-20	-21	-19	-17	-17	-19
20	0.5	-1	-3	-7	-7	-10	-8	-8	-9	-9	-9	-9	-7	-8	-6	-4	-4	-6
30	0.8	-1	-2	-6	-6	-8	-7	-6	-8	-7	-8	-7	-5	-6	-4	-2	-2	-4
40	1.0	-1	-2	-4	-4	-5	-4	-4	-4	-4	-4	-4	-3	-3	-2	1	0	-2
50	1.3	0	-2	-2	-2	-4	-2	-2	-3	-3	-2	-3	1	-2	1	0	1	-1
60	1.5	1	1	-3	-2	-3	-2	-2	-3	-2	-2	-3	1	-1	1	1	1	0
70	1.8	0	0	-2	1	-1	1	1	-1	1	-1	0	0	0	1	3	2	2
80	2.0	0	0	-1	1	-2	1	1	1	0	1	1	1	0	1	2	2	1
90	2.3	0	1	1	-1	-3	0	1	1	0	1	0	1	0	2	3	3	1
100	2.5	0	0	1	0	0	0	0	0	1	0	1	2	0	2	4	3	3
90	2.3	1	1	-1	1	1	1	1	0	0	1	1	1	0	2	3	3	0
80	2.0	0	1	-2	-1	-1	0	0	1	0	0	0	1	0	1	2	2	1
70	1.8	0	1	-2	1	-2	1	1	-1	1	-1	0	0	0	0	2	3	2
60	1.5	-1	-2	-3	-3	-3	-2	-2	-2	-2	-3	-2	1	-1	-1	1	0	0
50	1.3	-2	-2	-4	-3	-5	-3	-3	-3	-3	-2	-3	-2	-3	-2	0	0	0
40	1.0	-2	-2	-5	-4	-5	-4	-5	-5	-4	-5	-5	-3	-4	-3	1	-1	-2
30	0.8	-2	-4	-8	-7	-10	-7	-8	-8	-8	-8	-8	-6	-7	-5	-3	-3	-5
20	0.50	-3	-5	-9	-9	-11	-9	-9	-10	-10	-2	-10	-7	-9	-3	-5	-4	-6
10	0.25	-13	-15	-22	-21	-23	-21	-21	-23	-23	-23	-23	-21	-22	-20	-18	-18	-18
0	0.00																	

0.26% CO2

		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
		02/10/95	02/16/95	02/27/95	03/08/95	03/15/95	03/20/95	03/30/95	04/05/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/16/95	05/24/95	05/30/95	06/06/95
Stec	Expected			Calibrated	Calibrated	Calibrated						Calibrated						
0	0.000																	
10	0.025	-	-	-100	-100	-100	-100	-100	-100	-100	*	-100	-100	-100	-100	-100	-100	-100
20	0.050	-	-	-60	-62	-62	-83	-87	-75	-92	*	-100	-87	-67	-62	-62	-69	-71
30	0.075	-	-	-28	-28	-28	-53	-53	-45	-55	*	-60	-47	-50	-36	-35	-38	-40
40	0.100	-	-	-13	-13	-13	-36	-37	-31	-37	*	-41	-34	-35	-25	-25	-26	-28
50	0.125	-	-	-9	-9	-9	-28	-29	-25	-31	*	-33	-26	-28	-20	-18	-19	-22
60	0.150	-	-	-9	-6	-6	-25	-26	-24	-28	*	-29	-23	-24	-19	-17	-19	-21
70	0.175	-	-	-8	-7	-7	-24	-25	-21	-25	*	-26	-20	-22	-19	-15	-18	-20
80	0.200	-	-	-7	-7	-7	-23	-24	-21	-24	*	-25	-21	-21	-18	-17	-18	-19
90	0.225	-	-	-9	-7	-7	-23	-24	-21	-25	*	-26	-21	-22	-18	-17	-18	-20
100	0.250	-	-	-10	-3	-3	-23	-25	-22	-24	*	-24	-22	-23	-20	-19	-19	-20
90	0.225	-	-	-10	-8	-8	-24	-24	-21	-25	*	-25	-21	-22	-19	-17	-19	-19
80	0.200	-	-	-8	-7	-7	-23	-24	-22	-24	*	-25	-22	-22	-17	-17	-17	-19
70	0.175	-	-	-9	-7	-7	-24	-25	-21	-25	*	-26	-22	-24	-18	-16	-18	-19
60	0.150	-	-	-11	-9	-9	-26	-27	-23	-28	*	-28	-22	-24	-19	-17	-19	-21
50	0.125	-	-	-12	-12	-12	-29	-29	-25	-32	*	-33	-26	-28	-18	-18	-18	-22
40	0.100	-	-	-20	-17	-17	-35	-37	-33	-38	*	-40	-33	-34	-26	-24	-25	-29
30	0.075	-	-	-32	-32	-32	-49	-50	-44	-56	*	-60	-50	-51	-37	-35	-37	-38
20	0.050	-	-	-62	-69	-69	-83	-90	-75	-94	*	-100	-87	-85	-67	-62	-67	-69
10	0.025	-	-	-100	-100	-100	-100	-100	-100	-100	*	-100	-100	-100	-100	-100	-100	-100
0	0.000	-	-															

* User Error - Data and calibration loss. Recalibrated prior to week 7

FIGURE LEGENDS

Fig. 1.

Testing Setup. Setup showing how test gases were delivered to the analyzers via STEC device during testing.

Fig. 2a-e.

Short-term accuracy. Relative error for measurements from 1 to 8% CO_2 immediately after instrument calibration using 8% CO_2. Calibration and testing done weekly for 4 consecutive weeks.

Fig. 3a-e.

Response Curves. Analyzer response curves for 4 gas standards: 0.25, 2.5, 5, and 10% CO_2. Data from one week's short-term accuracy test. Relative error plotted vs. CO_2 concentration. Analyzer calibrated with 1 of the 4 standards. STEC gas divider then used to deliver 0 to 100 to 0% of the standard concentration. For the 8% standard, STEC was varied only from 0 to 80 to 0%, resulting in a maximum concentration of 8%.

Fig. 4a-e.

Long-term accuracy. Relative error for measurements from 0.25% to 8% over 13 weeks after a one-time calibration with 8% CO_2 at the beginning of the test.

Fig. 5a-b.

Ambient temperature. Effect of ambient temperature change on instrument measurement of 8% after calibration with the same. Instruments were tested first at ambient temperature (~20 °C), then 2 h after being cooled (~12 °C) or heated (~34 °C). Each instrument underwent 2 sequences of ambient, then cooling, then heating, and another 2 sequences of ambient, then heating, then cooling. Drift defines the change in instrument reading for each degree C.

Figure 1 Testing setup

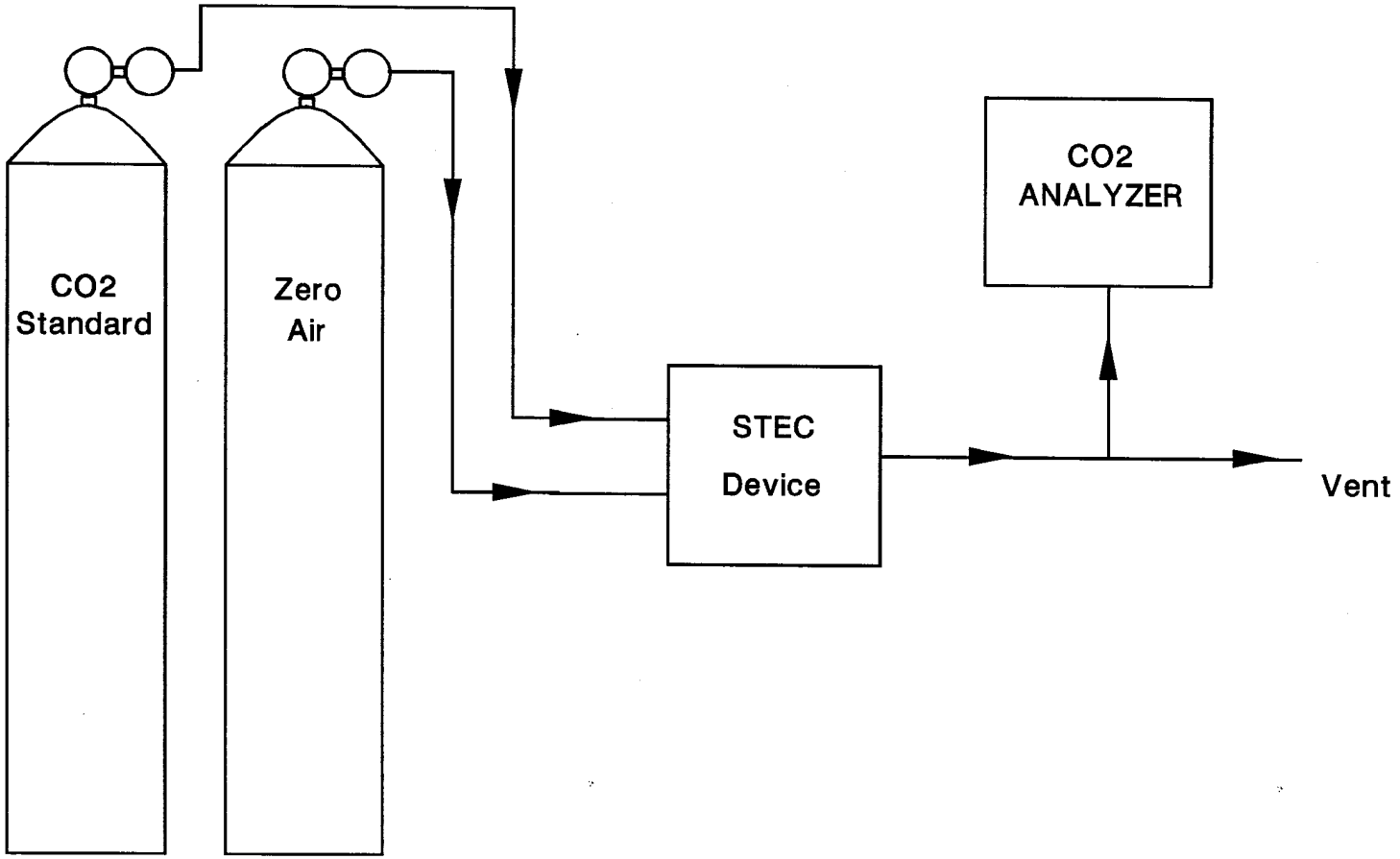


Figure 2A
Enmet Short-term Test

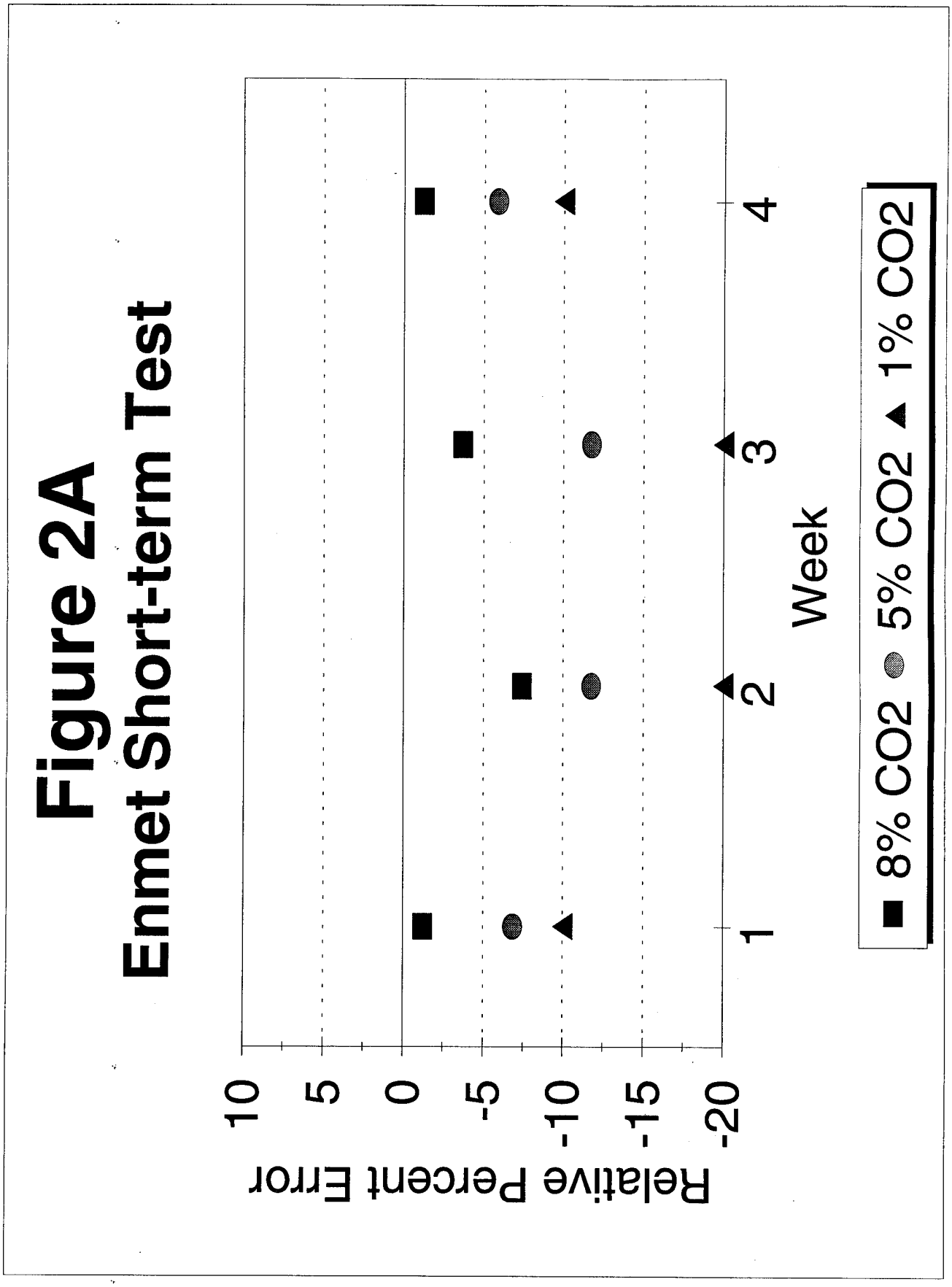


Figure 2B
RKI Short-term Test

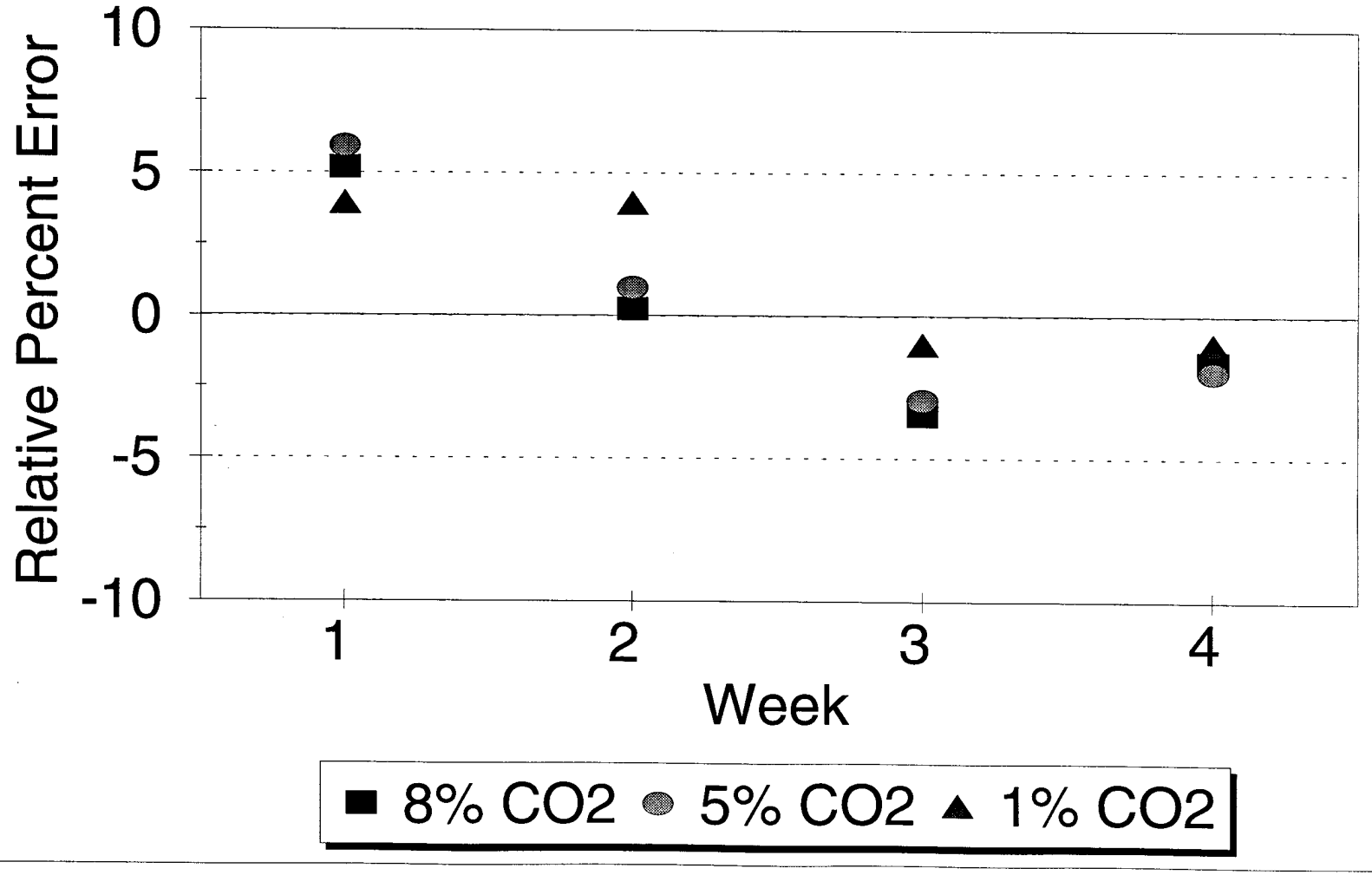


Figure 2C
Nova Short-term Test

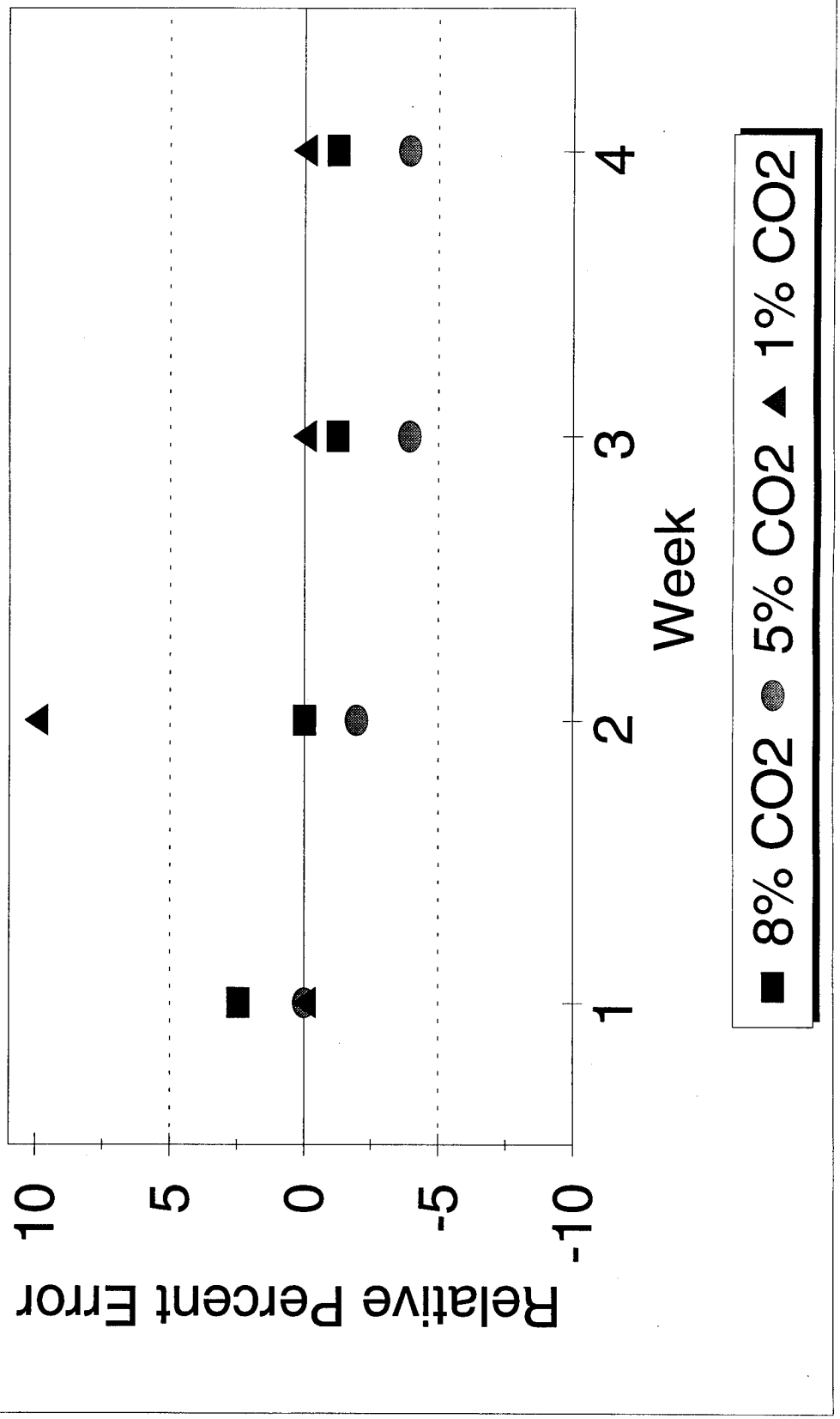


Figure 2D
GeoL Short-term Test

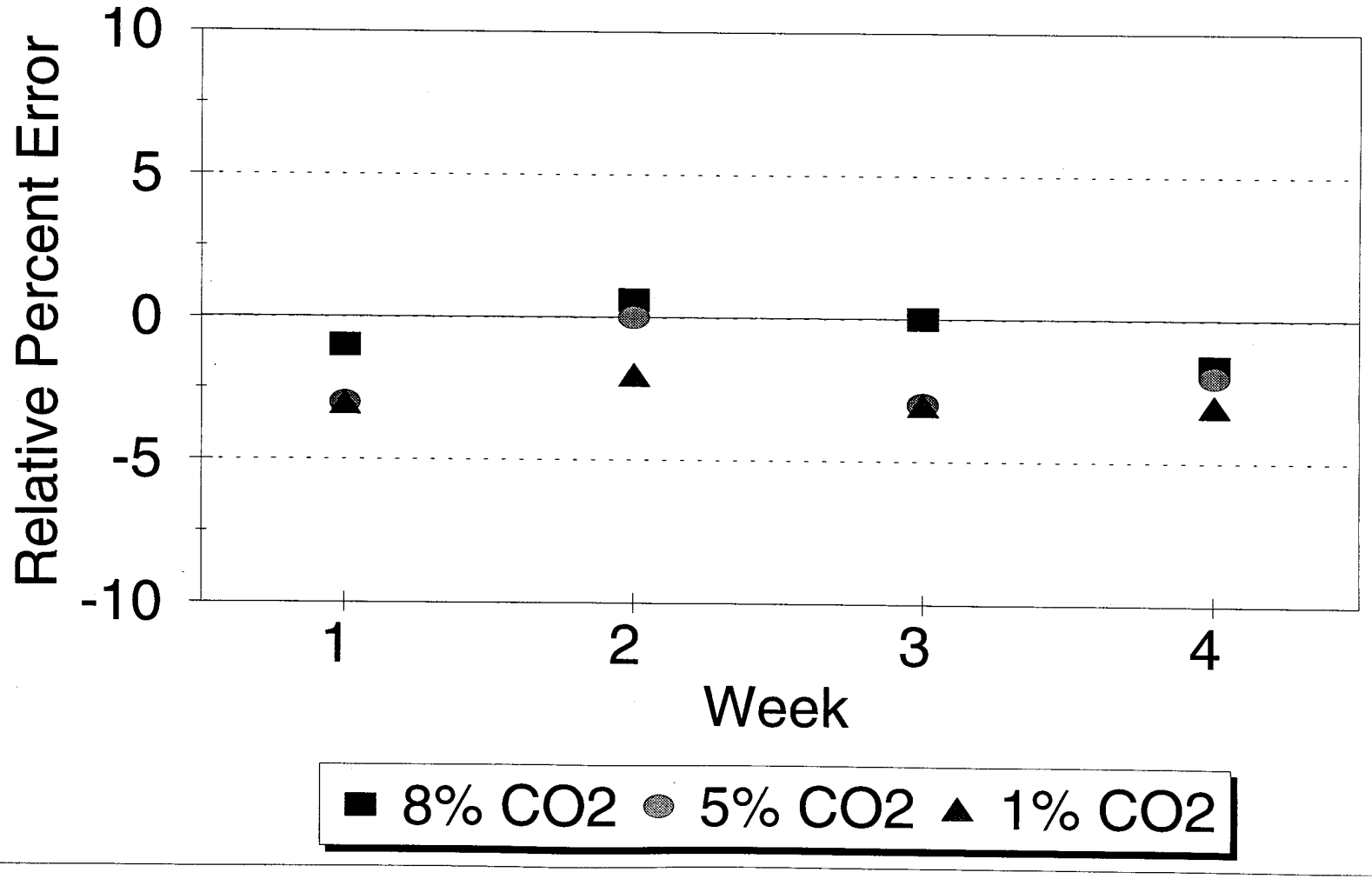


Figure 2E
GeoS Short-term Test

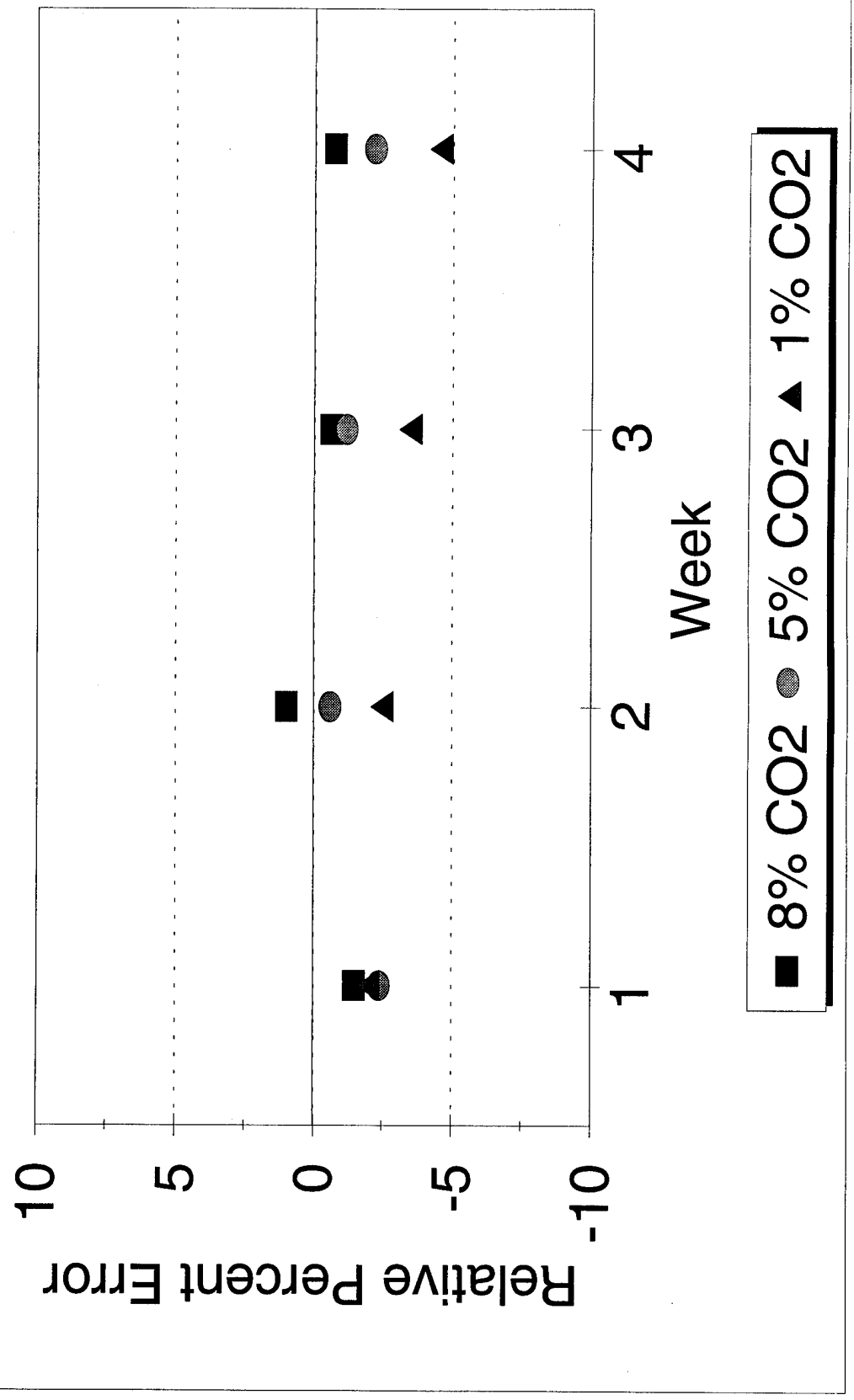


Figure 3A Enmet Response Curves

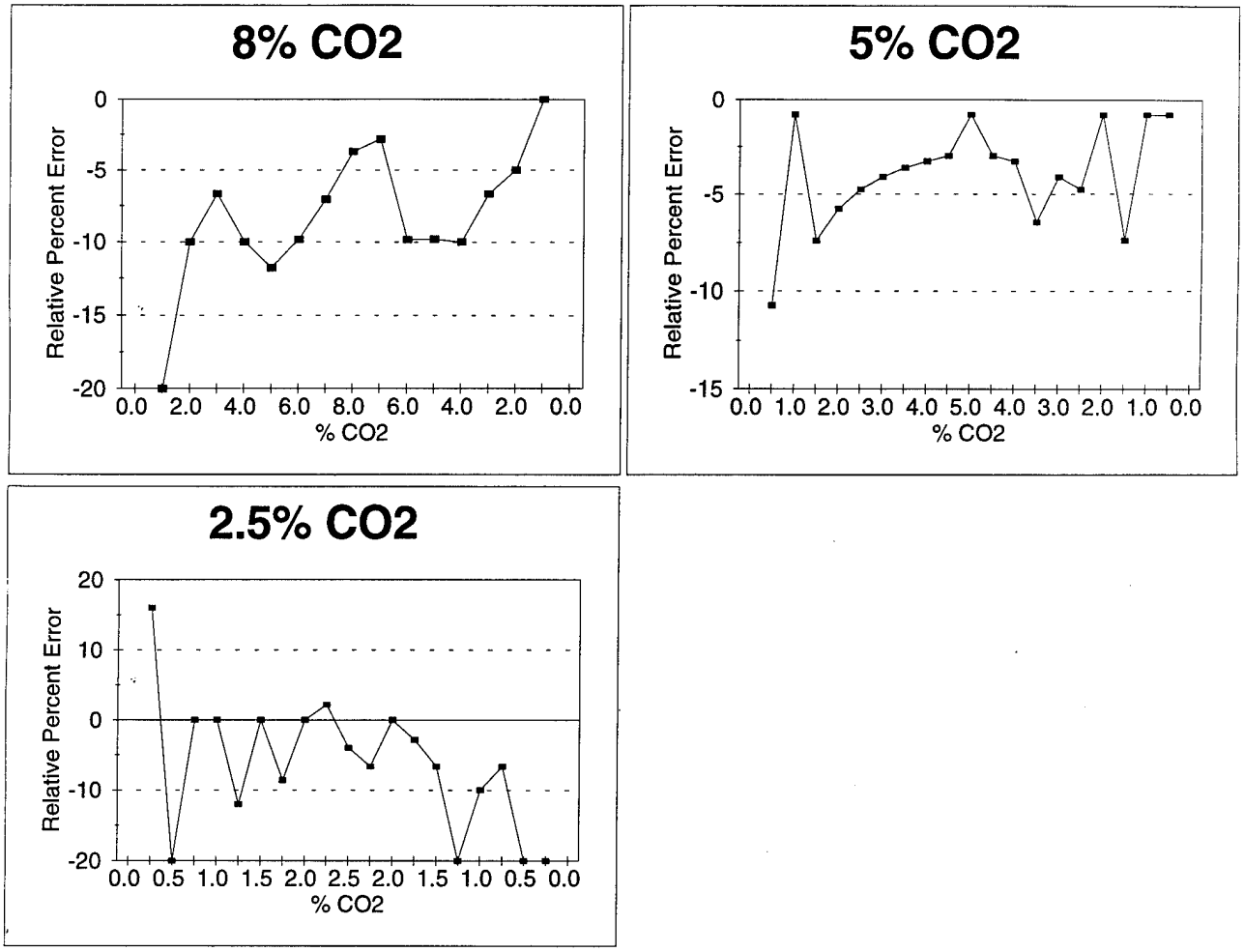


Figure 3B RKI Response Curves

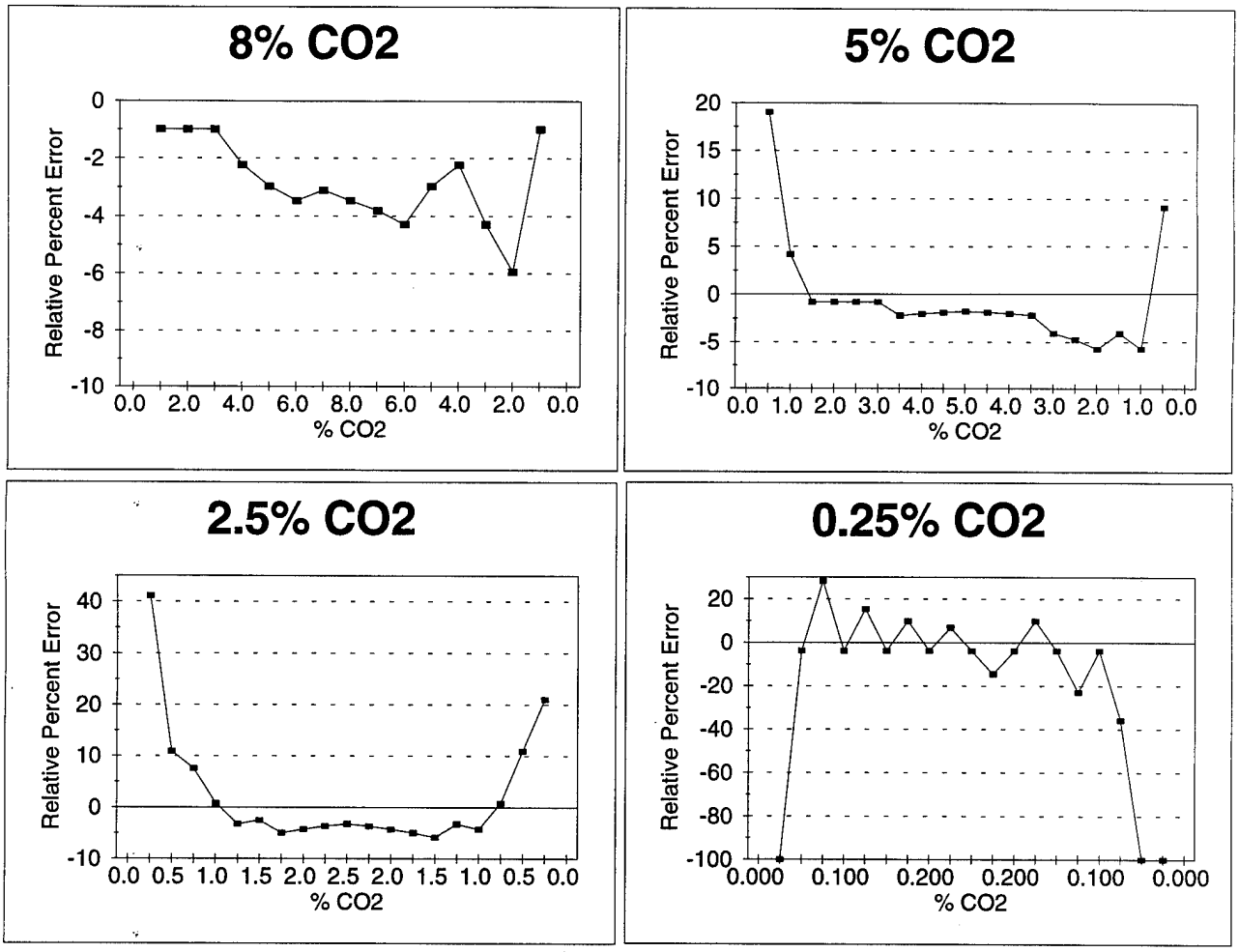
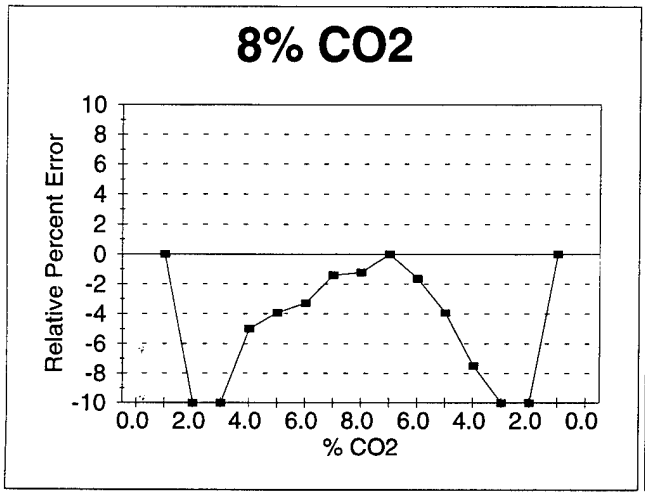
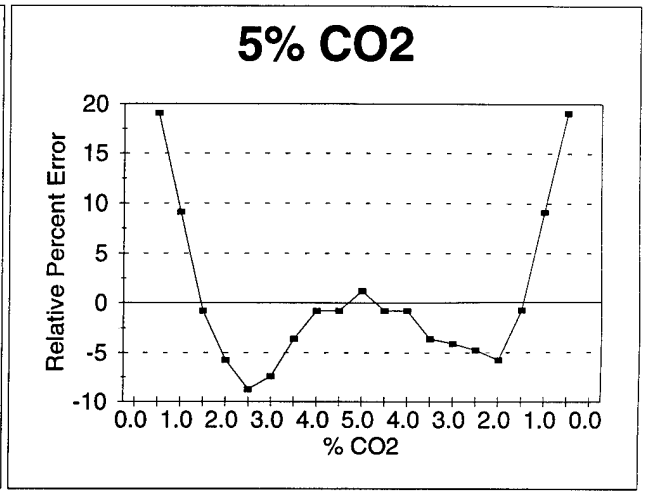


Figure 3C Nova Response Curves





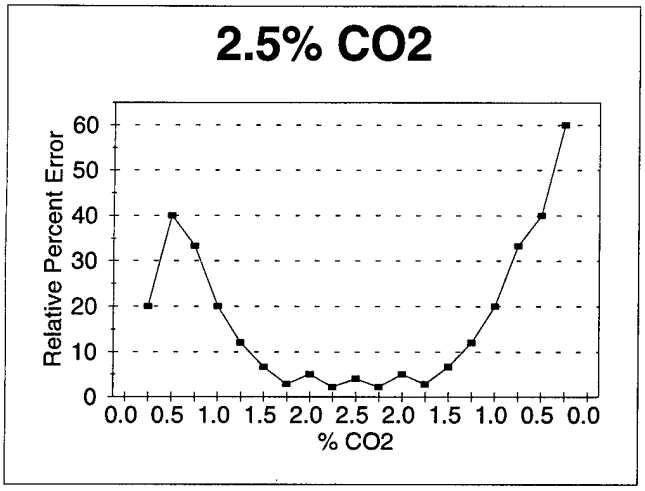


Figure 3D GeoL Response Curves

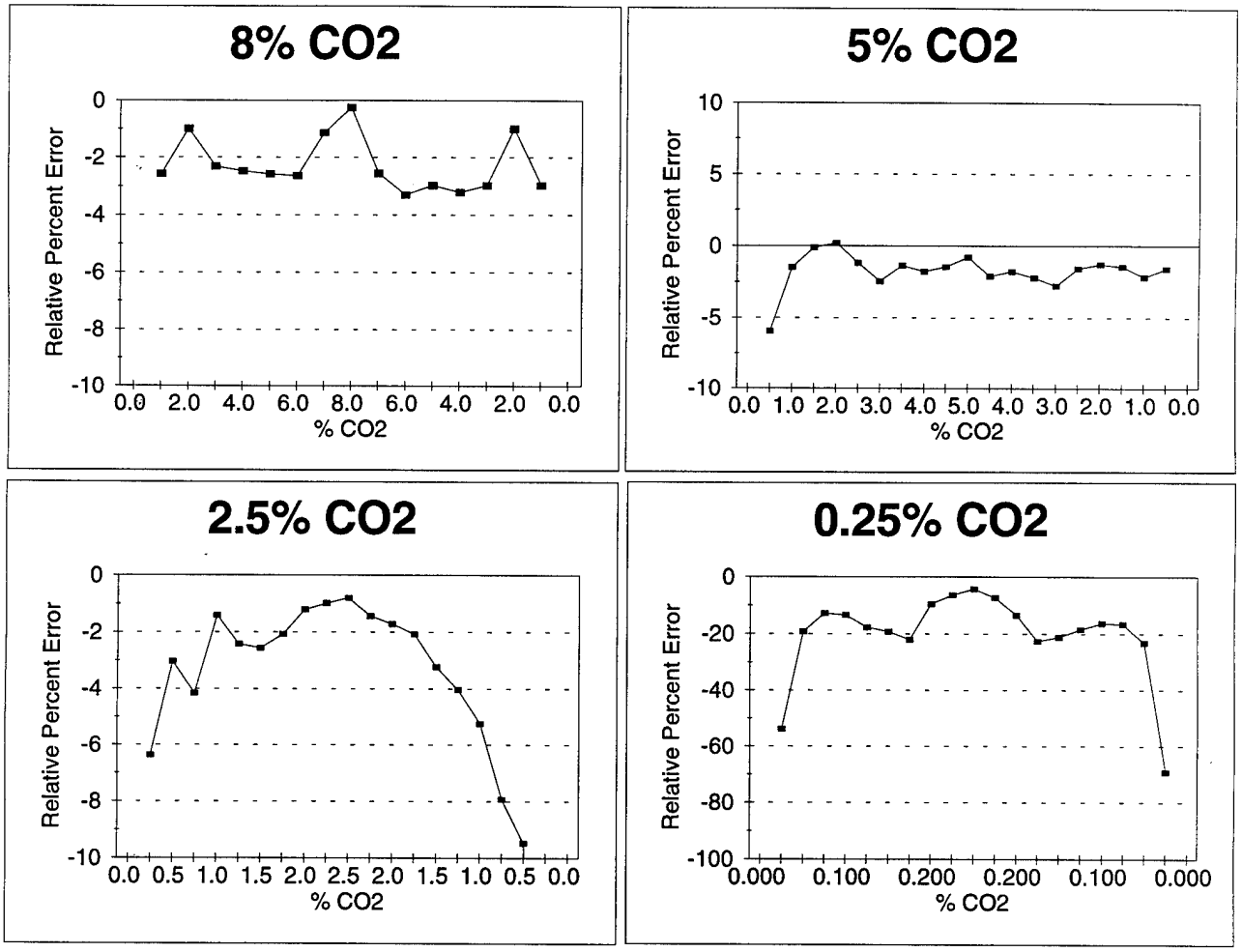


Figure 3E GeoS Response Curves

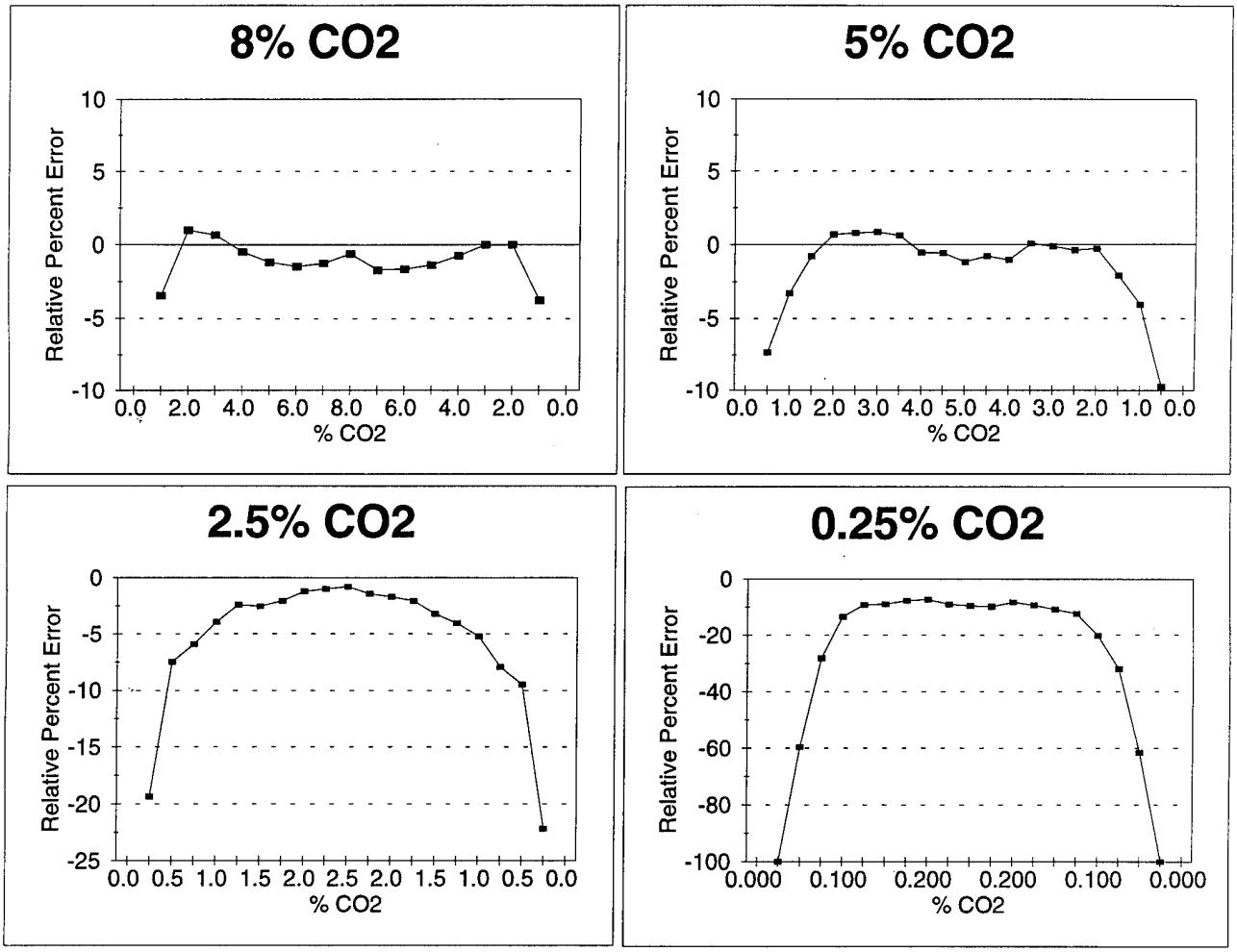


Figure 4A
Enmet Long-term Test

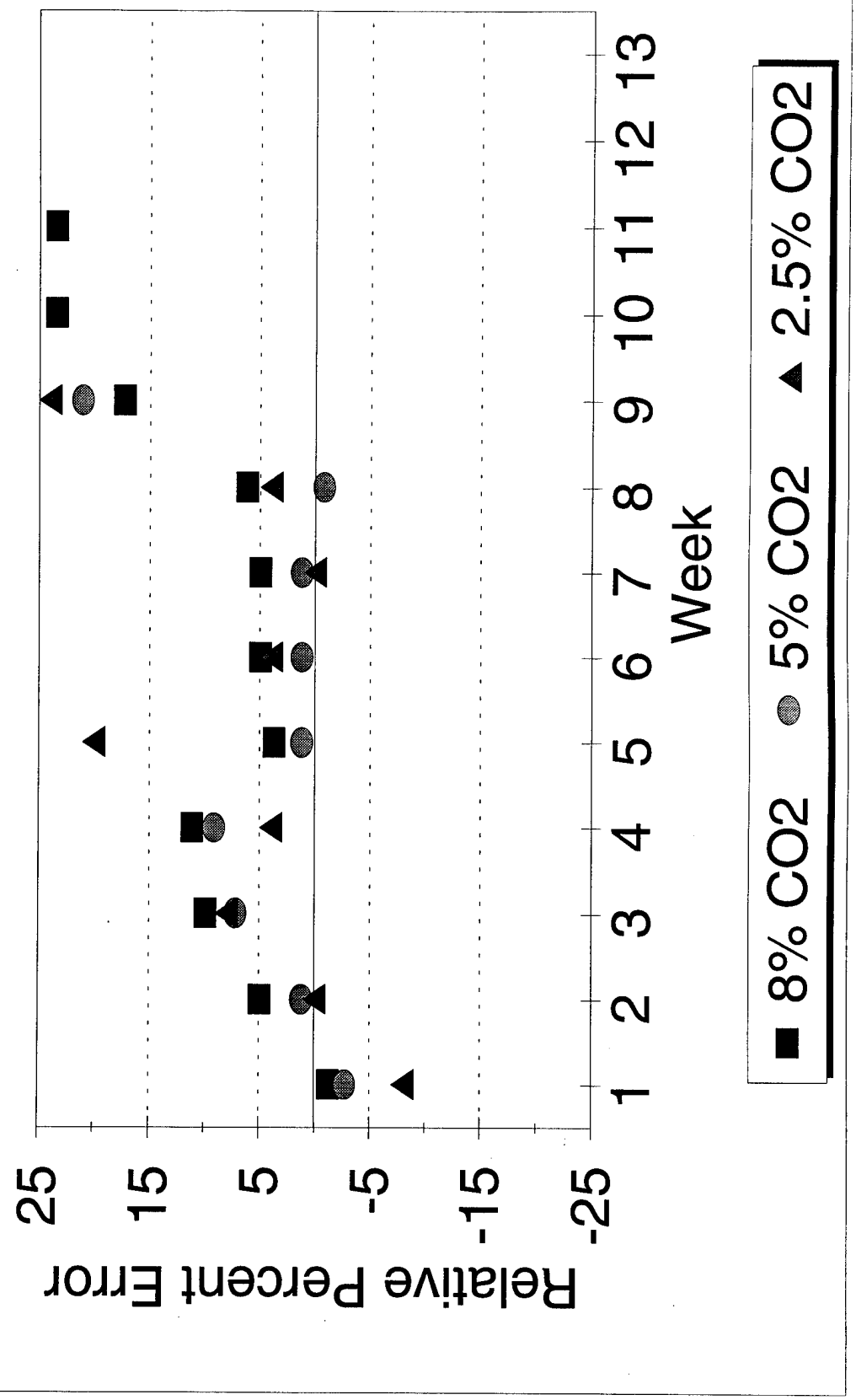


Figure 4B
RKI Long-term Test

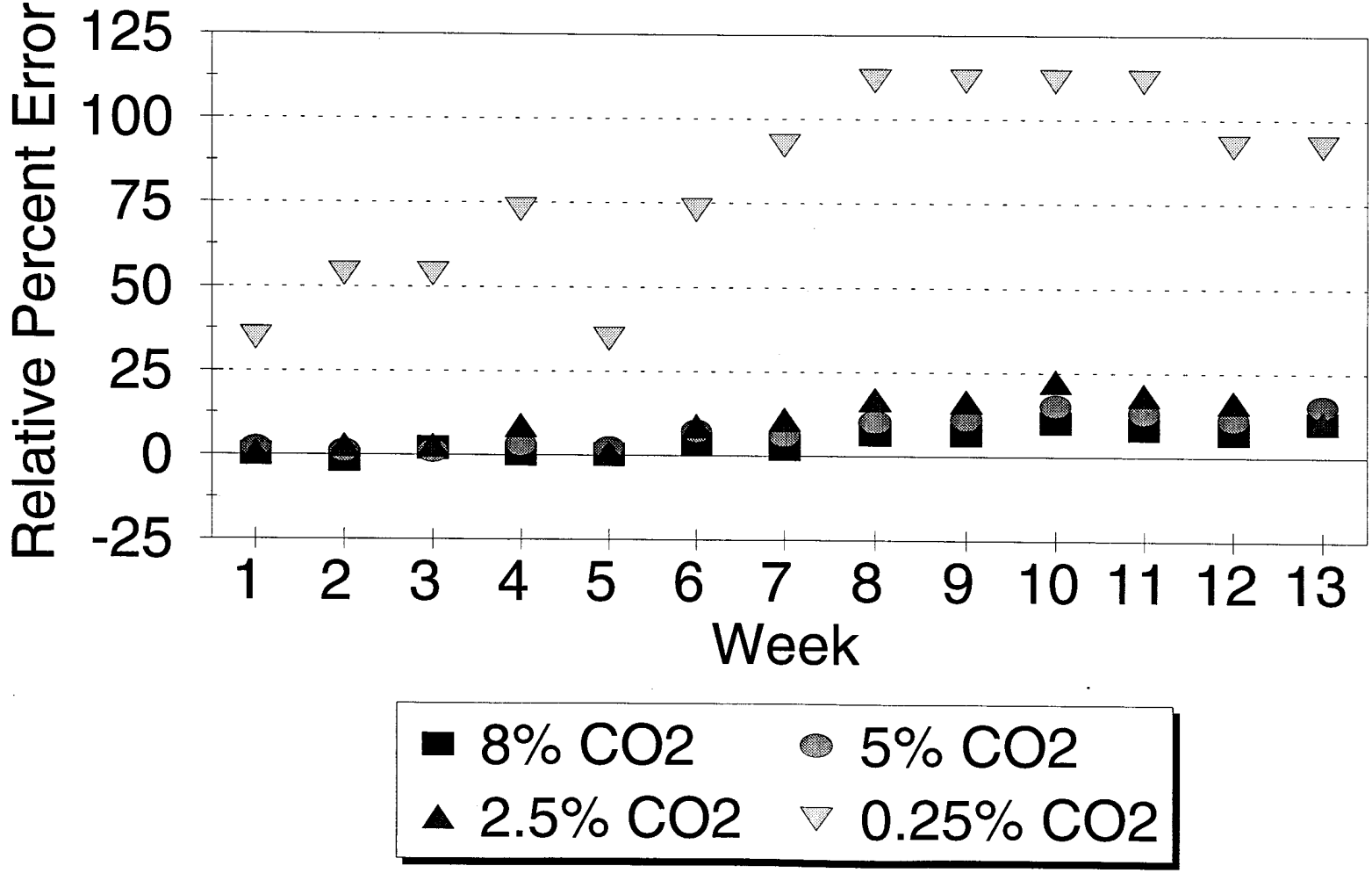


Figure 4C
Nova Long-term Test

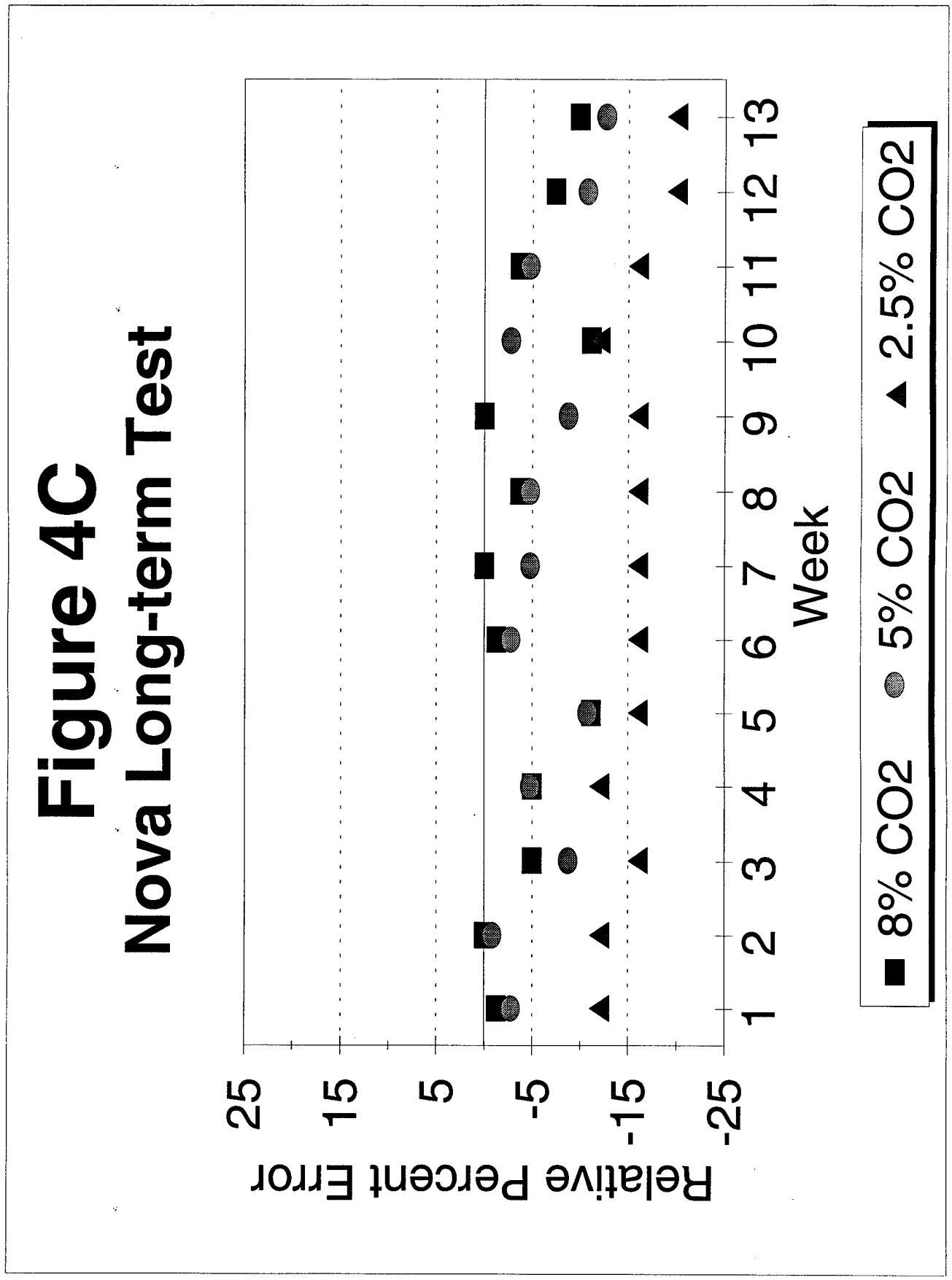


Figure 4D
GeoL Long-term Test

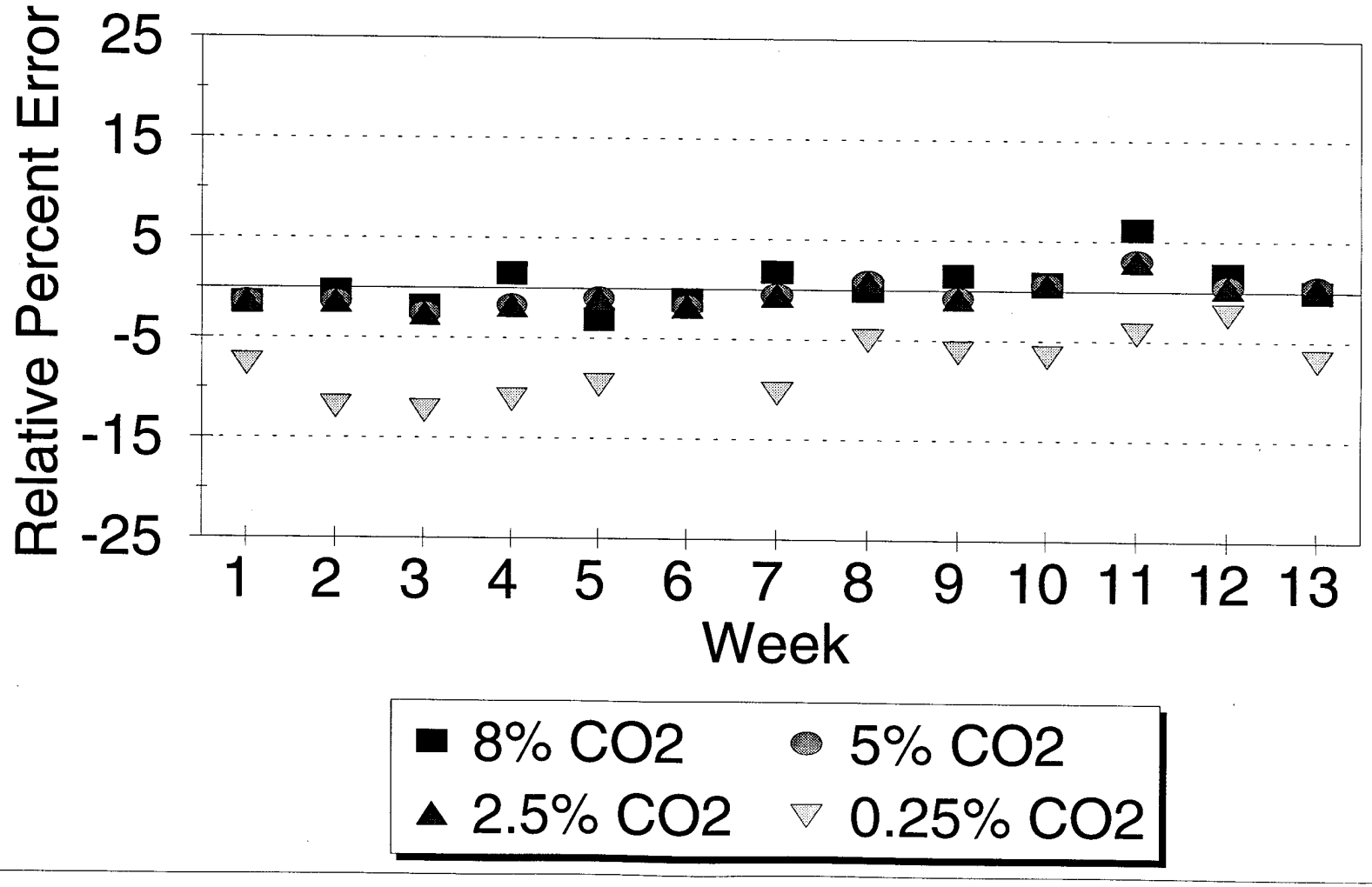


Figure 4E
GeoS Long-term Test

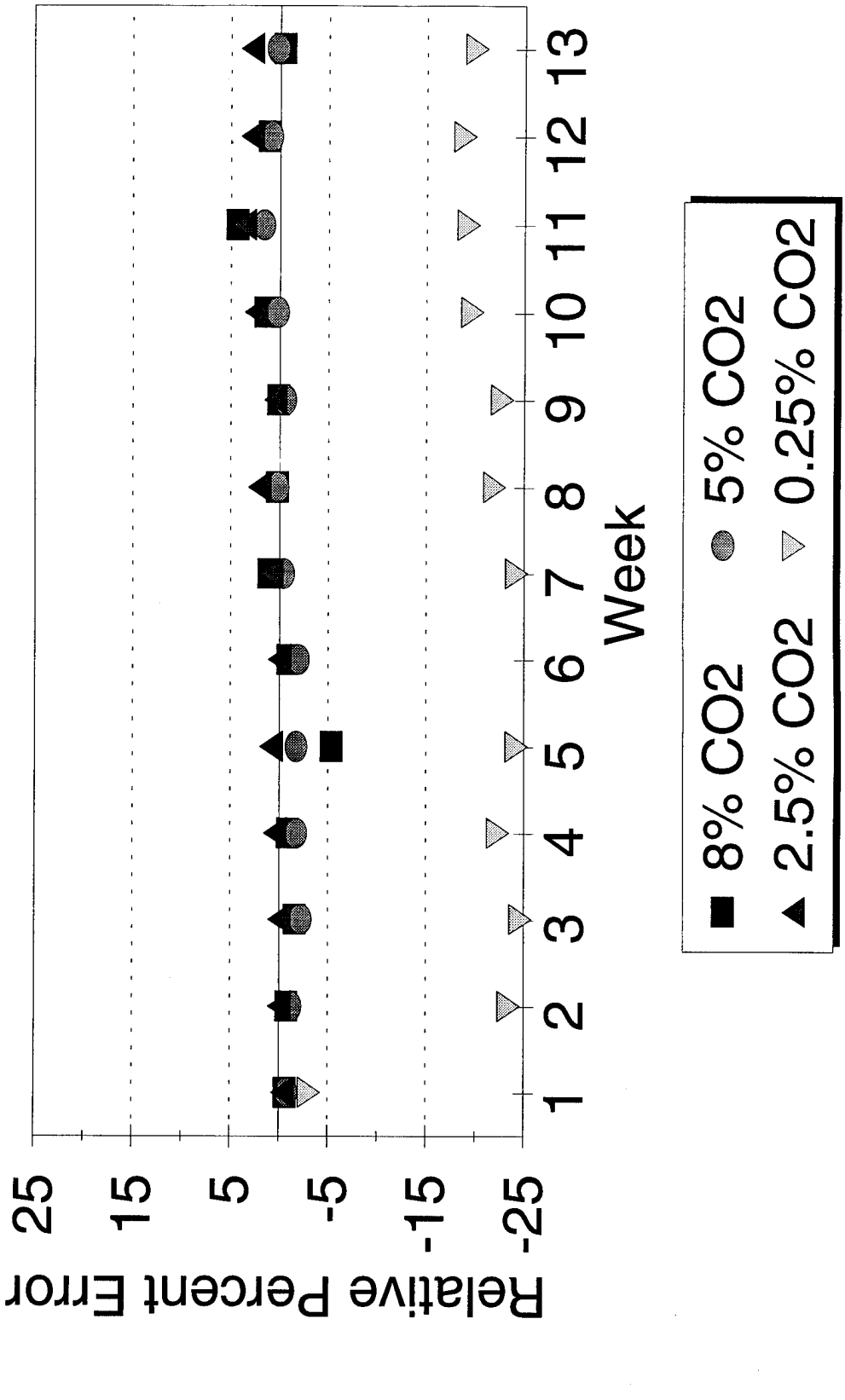


Figure 5A Temperature Test
8% CO2 - Drift / C

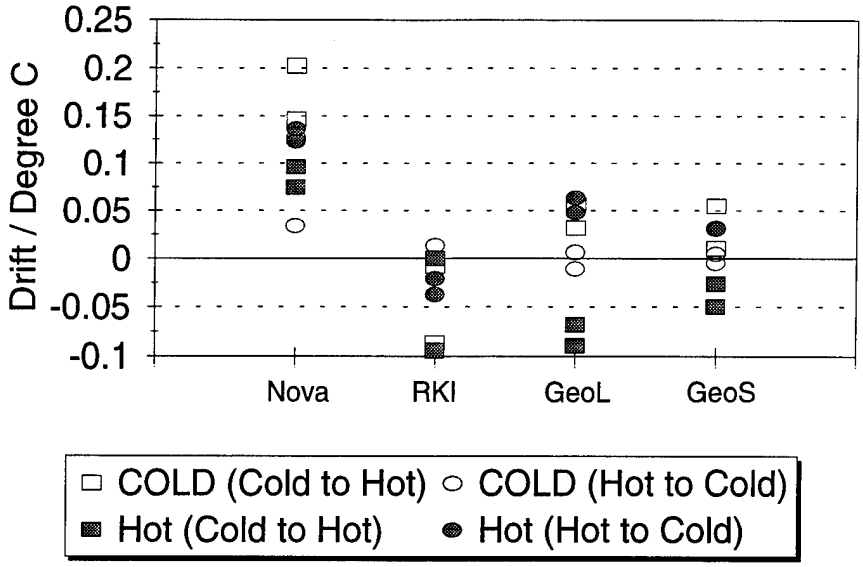
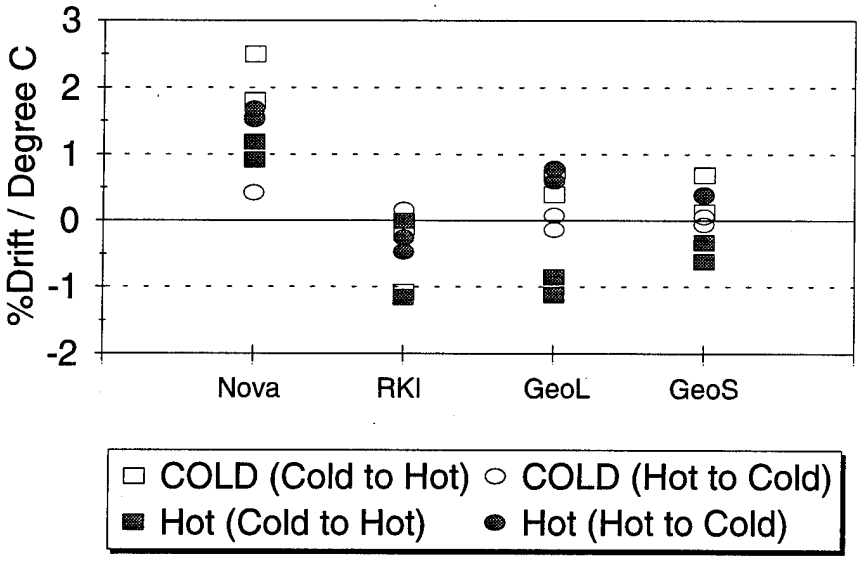


Figure 5B Temperature Test
8% CO2 - %Drift / C



APPENDIX A: INSTRUMENT REVIEW AND SELECTION.

The 5 candidates analyzers chosen for testing by NMRI are listed below.

PAGE		MANUFACTURER	MODEL
52		Enmet Corp.	CD-1300-P, 0 TO 10%
55	*	Geotechnical Inst. Inc.	CDM-1000/long, 0 to 7.5%
55		Geotechnical Inst. Inc.	CDM-1000/short, 0 to 7.5%
63		NOVA Analyt. Sys., Inc.	302 BD, 0 to 10%
64		RKI Instruments, Inc.	RIKEN RI-411A, 0 TO 9.95%

***SELECTED AS BEST OF ALL CANDIDATES**

The following vendors make instruments that are either portable or transportable. Only a few make units that are portable and cover the full 10.0% range. None operate under hyperbaric conditions. Vendors that were contacted but do not have applicable instruments are listed at the end of the Appendix.

PAGE		MANUFACTURER
50		California Analytical (formerly: Milton Roy)
51		Columbus Instruments, Div. International Instr. Co.
52	*	Enmet Corp.
53		Enviromax/Tess-com, Inc.
54		Gas Tech, Inc.
55	**	Geotechnical Instruments, Inc.
56		Horiba Instruments Inc.
57		Illinois Instruments, Inc.
58		Landtec Inc.
59		Li-Cor Inc.
60		Metrosonics Inc.
61		MSA Instr.
62		National Draeger, Inc.
63	*	NOVA Analytical Systems, Inc.
64	*	RKI Instruments, Inc.
65		Sensidine, Inc.
66		Servomex Co.
67		Shimadzu Scientific Instruments, Inc.
68		Siemens Industrial Automation, Inc.
69		Telaire Systems, Inc.
70		Teledyne Brown Engineering, Analytical Instruments.

* Tested as a candidate analyzer.
** Tested and selected as the final and best of all candidates.

California Analytical (formerly:Milton Roy) **Attn: Fred Christ**
1238 West Grove Ave.
Orange, CA 92665-4134
(714)-974-5560 FAX (714)-921-2531

Model:	ZFP-5
Price:	$2990.00
Method:	NDIR
Ranges:	0-2000, 0-5000 PPM, 0 to 2 % & 0 to 5 %(dual range)
Power:	115 Vac or rechargeable battery
Sampling pump:	built in/10 s response
Alarms:	none
Display:	Analog
Accuracy:	± 5% of full scale
Repeatability:	± 5% of full scale
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	32-104 °F (0-40°C)
Storage temp:	not specified
Weight:	13 lbs. (6 kg.)
Dims:	8.5x6.1x10.4 in. (215x155x265mm)
Output signal:	0-100mV DC
Calibration:	not specified
Cal controls:	zero & span

TEST RESULTS: On 1/21/92 the unit was briefly tested at NMRI/Lab 103. The test consisted of a few zero and span measurements which were within the stated accuracy on both ranges. The unit was placed in a small animal hyperbaric chamber and pressed to 100 FSW, during a short exposure (less than 10 minutes), the unit read a steady value (400 PPM). The unit was returned to room pressure and retests showed normal operation.

Columbus Instruments, Div. International Instr. Co.
950 N. Haque Ave.
P.O. Box 44049
Columbus, OH 43204
(800)669-5011
Fax (614)276-0529

Model:	Model-180/8200-D-30/8203-D-30
Price:	$4,900.00
Method:	NDIR
Ranges:	0-10%
Power:	115 Vac only
Sampling Pump:	Internal/100-650 ml/min
Alarms:	none
Display:	digital
Accuracy:	± .01%
Repeatability:	± .04%
Zero drift at constant temp:	.03%
Zero drift temp effect:	
Operating temp range:	
Storage temp:	
Weight:	22 lb/9.75 kg
Dims:	11x11.5x14 in.
Output signal:	
Calibration:	?
Cal controls:	zero/span

TEST RESULTS: None

COMMENTS: This is a "high accuracy" unit not suitable for this study.

ENMET CORP.
P.O. BOX 97
680 Fairfield Ct.
ANN ARBOR, MI 48867-0979
(313)-761-1270 Fax (313)-761-3220

Model:	CD-1300-P portable carbon dioxide analyzer
Price:	$1895.00
Method:	NDIR
Ranges:	Std,0-5000PPM, Opt, 0-10%, 0-20%, 0-100%
Power:	9.6V rechargeable batt, operates 12 h on 1 charge, can be operated off of charger
Sampling pump:	built in with 500 cc/min flow
Alarms:	high & low gas, low flow
Display:	Analog
Accuracy:	±3% of full scale
Repeatability:	±1% of full scale
Zero drift at constant temp:	<0.2% CO_2 per mo.
Zero drift temp effect:	<0.2% CO_2 per deg. C
Operating temp range:	15 to 140 °F (-10 to 60 °C)
Storage temp:	-5 to 160 °F (-20 to 70 °C)
Weight:	3.5 lb (1.5 kg.)
Dims:	3x5x8.5 in. (7.5x14x22cm.)
Output signal:	0-1Vdc (0 to full scale, non-linear)
Calibration:	Every 3 to 4 months
Cal controls:	zero & span

TEST RESULTS: Difficult to calibrate.

Enviromax/Tess-Com, Inc.
18900 Teller Ave.
Irvine, CA 92715
(714)863-9443
Fax (714)756-1635

Distributor:
Tess-Com/Lou Colonna
Butler, PA
(412)233-5782

Model:	*enviromax* 3000
Price:	$6395.00
Method:	NDIR
Ranges:	0-10,000 PPM
Power:	Battery/rechargeable
Sampling Pump:	internal, 0.2-2 LPM
Alarms:	audible
Display:	digital
Accuracy:	± 3 ppm or 0.1% of full scale
Repeatability:	± 3 ppm
Zero drift at constant temp:	<3 ppm per 24 h
Zero drift temp effect:	not specified
Operating temp range:	-10 to 50 °C
Storage temp:	-10 to 80 °C
Weight:	22 lbs. (10 kg)
Dims:	20x8x5 in. (50x22x13)
Output signal:	0-1,5,10Vdc
Calibration:	not specified
Cal controls:	zero/span

TEST RESULTS: none, but the navy has one in a Norfolk, VA facility.

COMMENTS: Agent claims the unit is "top of the line & state of the art", more data needed, price seems very high for this study. Demo available for portable and rack mounted CO_2/O_2 version.

Gas Tech, Inc.
8407 Central Ave.
Newark, CA 94560-3431
(510)745-8700
Fax (510)794-6201

Distributor:
Jay Mottley.
Carey Machinery, Co
3501 Brehns Ave.
Baltimore, MD 21213
(410) 485-2323

Model:	3252 Carbon Dioxide GasTechtor
Price:	$3100.00
Method:	NDIR
Ranges:	0 to 5% CO_2 and 0 to 25% O_2 is the only version made
Power:	Rechargeable battery
Sampling Pump:	built in
Alarms:	variable level
Display:	analog
Accuracy:	± 10% 0f full scale
Repeatability:	± 5% of full scale
Zero drift at constant temp:	no info
Zero drift temp effect:	no info
Operating temp range:	0-40 °C
Storage temp:	no info
Weight:	8 lbs
Dims:	12x4x6 in.
Output signal:	optional, 0-100mV
Calibration:	no info
Cal controls:	no info

TEST RESULTS: none

COMMENTS: The vendor only markets a dual sensor CO_2/O_2 unit and the range is 0 to 5% which is too low for this application. One unit has been procured for the DDS project for evaluation as a backup unit.

Geotechnical Instruments, Inc
7507 Standish Pl.
Rockville, MD 20855
(301)309-6580
Fax (301)309-6584

Distributor:
Joel Johnson
PEDC, Inc.
P.O. Box 7026
Wilmington, DE 19803
(302) 655-9291 Fax 655-8140

Model:	CDM-1000
Price:	$4300.00
Method:	NDIR
Ranges:	0 to 7.5%
Power:	Battery/115Vac on recharger
Sampling Pump:	Internal @ 500-750 cc/min
Alarms:	none
Display:	digital
Accuracy:	± 10% of measurement/verified
Repeatability:	± 10% of measurement/verified
Zero drift at constant temp:	not checked
Zero drift temp effect:	~+10 ppm/-1°F
Operating temp range:	0-40 °C/32-104 °F
Storage temp:	
Weight:	4.8 lb./2.2 kg
Dims:	8.7x8.9x2 in./22x22.6x5.1 cm.
Output signal:	RS 232
Calibration:	TBD
Cal controls:	Span only

TEST RESULTS: Tested 10/25/94. Accuracy/Repeatability/drift tests on low/high, 1,250/20,000 PPM gas showed that the unit has a maximum error of ± 3% @ 1,250 PPM and ± 7% @ 20,000 PPM.Linearity tests from 500-2,500 PPM were ± 5%(below 500 PPM the error was 20%). From 5,000-25,000 PPM, the linearity was ± 6%.Zero/span checks were within spec for 2 days, then the zero became offset by 600 PPM. After a 48 hour off cycle, the zero returned to normal. A telecon with Chris Sweet (Geotch. U.K.) indicated the problem may have been infusion of the 25,000PPM span gas into the interior of the case. It then takes time for this gas to exit since the case is sealed with a gasket. This fault has been corrected.

Horiba Instruments Inc.
1021 Duryea Ave.
Irvine, CA 92714
(800)-446-7422
Fax (714)-250-0924

Sales/Distributor:
PENN-DEL
810 N. Pine Ridge Ct.
Bel Air, MD 21014
(410)-893-7960

R.T. Gondon
(410)437-8785
(410)437-8785

Model:	MEXA-211GE
Price:	$1995.00
Method:	NDIR
Ranges:	0-19.995
Power:	120Vac, not battery operated
Sampling pump:	built in
Alarms:	multiple, gas, etc.
Display:	digital
Accuracy:	± (not avail)
Repeatability:	± 0.3% or ± 2%, whichever is greater
Zero drift at constant temp:	(not avail)
Zero drift temp effect:	(not avail)
Operating temp range:	0-40 °C
Storage temp:	(not avail)
Weight:	approx 14.4 lb (6.5 kg)
Dims:	10.3x6.3x14.2 in. (260x160x360cm.)
Output signal:	0-1Vdc
Calibration:	not specified
Cal controls:	not specified

TEST RESULTS: none

COMMENTS: Demonstration requested 8/22/94. R. Gondon sent Horiba a second request for a demo 11/1/94.

Illinois Instruments, Inc.
27840 Concrete Dr.
Ingleside, IL 60041
(815)-344-6212
Fax (815)-344-6332

Model:	3700 Headspace Analyzer
Price:	$4495.00
Method:	NDIR
Ranges:	0-100%
Power:	115Vac only
Sampling Pump:	internal
Alarms:	none
Display:	digital
Accuracy:	± 2% of measured value
Repeatability:	not specified
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	not specified
Storage temp:	not defined
Weight:	not given
Dims:	11x10.5x4.5 in.
Output signal:	0-10V
Calibration:	not specified
Cal controls:	zero & span

TEST RESULTS: none

COMMENTS: No battery option; demo available if desired.

Landtec
6055 E Washington Blvd.
Commerce, CA

Distributor:
Hazco services Inc.
2006 Springboro West
Dayton, OH 45439
(513)-293-2700
Fax (513)-293-9227
Hot line (800)-332-0435

Model:	GA-90 Gas Analyzer
Price:	$4875.00
Method:	NDIR
Ranges:	0-75%
Power:	Battery only ?
Sampling Pump:	Internal
Alarms:	wet gas
Display:	digital
Accuracy:	± 3%(per telecon, in 0-10% may be o.k.)
Repeatability:	not specified
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	32 - 104 °F
Storage temp:	not specified
Weight:	"light weight"
Dims:	"compact"
Output signal:	none
Calibration:	not specified
Cal controls:	not described

TEST RESULTS: No test.

COMMENTS: This unit is made by Geotechnical Instruments and is similar to Geotechnical CDM-1000. Landtec is the U.S. distributor.

LI-COR, Inc.
4421 Superior St.
P.O. Box 4425
Lincoln, NE 68504
(800)-447-3576 (402)-467-3576 FAX (402)-467-2819

Model:	LI-6252/LI-670
Price:	$7300.00/$2375.00
Method:	NDIR
Ranges:	0-1000 & 0-5000 ppm
Power:	120 Vac & rechargeable batt. pack (10.5 - 16Vdc)
Sampling pump:	dual, variable flow, for sample & reference (if needed)
Alarms:	none
Display:	digital
Accuracy:	±5 ppm
Repeatability:	±1 ppm
Zero drift at constant temp:	<10 ppm per 24 h
Zero drift temp effect:	0.5 ppm per °C
Operating temp range:	not specified
Storage temp:	not specified
Weight:	7.7 lb (3.5 kg.)
Dims:	13x33.5x24cm.
Output signal:	RS-232c,100mV,5V,±15V (non-linear) & 4-20 mA
Calibration:	daily
Cal controls:	Zero, span

TEST RESULTS: A 6252/670 combination has been used for 2 years as a bench top unit with no problems. Accuracy and stability are to specification.

COMMENTS: This system is NOT rugged, corpsman friendly or low cost. This system should be used as a performance standard with which candidate analyzers should be compared.

Metrosonics Inc.
General Products Div.
P.O. Box 23075
Rochester, NY 14692
(716)-334-7300
Fax (716)-334-2635

Distributor
NCP/Analytical Inst. Inc.
512 Interchange Blvd.
Newark, DE 19711
(800)-346-0304
Fax (302)-733-0948

Model:	aq-511
Price:	$2290.00 (with batt. pack)
Method:	NDIR
Ranges:	0-5000 ppm
Power:	114Vac & battery pack
Sampling Pump:	Internal @ 1 LPM
Alarms:	high gas option
Display:	digital
Accuracy:	± 3% of full scale
Repeatability:	± not specified
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	32 - 122 °F (0-50 °C)
Storage temp:	-4 - 140 °F ((-20)-60 °C)
Weight:	8.2 lb (3.7 kg)
Dims:	10.1x12.3x4 in. (25.7x31.2x10.3 cm)
Output signal:	0 - 1V
Calibration:	daily
Cal controls:	Zero & span

TEST RESULTS: None

COMMENTS: This unit does not cover the full range (7.5%)

MSA Instruments
P.O. Box 426
Pittsburgh, PA 15230
(800)-672-2222

Portable Regional Office
MSA/36 Great Valley Rd.
Malvern, PA 19355
(800)-672-2222 (ask for Malvrn)
FAX (610)-647-8893

Model:	ACO_2 Hand Held Indicator
Price:	$1600.00
Method:	Electrochemical pH sensor
Ranges:	0.03% to100%
Power:	4AA batteries
Sampling Pump:	diffusion or hand pump
Alarms:	dual gas levels & low battery
Display:	digital
Accuracy:	± 0.02% @ 10% range
Repeatability:	± not specified
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	32-113 °F (0-45 °C)
Operating Pressure range:	700-1060 hPa
Storage temp:	not specified
Weight:	11 oz. (310 gm.)
Dims:	2.3x1.6x6.2 in. (60x42x160 cm.)
Output signal:	none
Calibration:	unknown
Cal controls:	not specified

TEST RESULTS: none

COMMENTS: sensor life is one year; electrolyte must be replaced every 3 mos.

National Draeger, Inc.
101 Technology Dr.
P.O. Box 120
Pittsburgh, PA 15230
(800)-922-5518
Fax (800)-922-5519

Distributor:
NCP/Analytical Instr. Inc.
512 Interchange Blvd.
Newark, DE 19711
(800)-346-0304
(302)-733-0948

Model:	Multiwarn Portable Gas Monitor
Price:	$5300.00
Method:	Unknown
Ranges:	0-9999 PPM
Power:	Battery only
Sampling Pump:	Internal and diffusion
Alarms:	low flow and gas
Display:	digital
Accuracy:	no data
Repeatability:	no data
Zero drift at constant temp:	no data
Zero drift temp effect:	no data
Operating temp range:	(-5)- 105 °F (-20 to 40 °C)
Storage temp:	not specified
Weight:	3.1 lbs. (1.4 kg)
Dims:	4.9x7.5x2.5 in. (12.4x19.0x6.3 cm)
Output signal:	PC interface
Calibration:	unknown
Cal controls:	unknown

TEST RESULTS: none

COMMENTS: Pricey...Demo requested 9/12/94

NOVA Analytical Systems, Inc.
1925 Pine Ave.
Niagra Falls, NY 14301
(800)295-3771
Fax (716)282-2937

Model:	302BD Portable CO_2 Analyzer
Price:	$2645.00
Method:	NDIR
Ranges:	0-10%
Power:	115Vac & battery
Sampling Pump:	internal/
Alarms:	none
Display:	digital
Accuracy:	± 2% of full scale
Repeatability:	± 2% of full scale
Zero drift at constant temp:	30 ppm per hour
Zero drift temp effect:	2 ppm per deg. F
Operating temp range:	32-120 °F (0-50 °C)
Storage temp:	-20 to 130 °F (-30 to 55 °C)
Weight:	6 lb
Dims:	10x7.5x8 in.
Output signal:	0-1Vdc
Calibration:	suggested "yearly"
Cal controls:	span only

TEST RESULTS: During screening, the unit performed within 10% from 1 to 5%. Below 1%, the error was 20%. Accuracy & repeatability were better than 5%. Drift, short term, is not as good as desired, but is well within the required range. A daily calibration span check after a 30 min warm-up is recommended for best results.

RKI Instr. Inc.
1855 Whipple Rd.
Hayward, CA 94544
(800)754-5165
Fax(510)441-5650

Distributor

Advanced Control Technology
P.O. Box 85
2151 Johnson Rd.
Rockville, VA 23146
(804)-749-3434

Model:	RIKEN RI-411A
Price:	$3075.00
Method:	NDIR
Ranges:	0-10%
Power:	120Vac & batt. pack
Sampling Pump:	Internal diaphragm (1.2 LPM)
Alarms:	High CO_2 & Low batt
Display:	digital
Accuracy:	± 2% of full scale
Repeatability:	± 2% of full scale
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	14-104 °F (-10-40 °C)
Storage temp:	not specified
Weight:	6 lb
Dims:	10x7.5x4.5 in.
Output signal:	0-10 Vdc linear
Calibration:	Based on tests, a daily check is desirable
Cal controls:	Zero & Span

TEST RESULTS: The loaner tested did not have a 115Vac adapter so all tests were done with alkaline batteries. Linearity, accuracy and repeatability were within 5%. Even long term, zero drift was excellent.

Sensidine, Inc.
16333 Bay Vista Dr.
Clearwater, FL 34620
(800)-451-9444
Fax (813)-539-0550

Model:	SS2000, Portable Gas Detector
Price:	???
Method:	Electrochemical
Ranges:	1,000-10,000 PPM
Power:	Battery/optional 115Vac
Sampling Pump:	none/diffusion
Alarms:	5,000 ppm
Display:	analog
Accuracy:	± 10%
Repeatability:	± 10%
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	23-113 °F (-5 - 45 °C)
Storage temp:	not specified
Weight:	3.4 lbs. (1.5kg)
Dims:	8.5x4.4x6.8 in. (21.6x10.9x17.3 cm)
Output signal:	none
Calibration:	not specified
Cal controls:	not defined

TEST RESULTS: none

COMMENTS: electrochemical sensor has 3 year life. The lower range seems to start at 1000 PPM, more info is needed.

Servomex Co.
90 Kerry Pl.
Norwood, MA 02062
(617)-769-7710 FAX(617)-769-2834

Model:	PA404
Price:	$7500.00
Method:	NDIR
Ranges:	Varied, 0-10% available
Power:	120Vac & internal batt
Sampling Pump:	Internal (0.1-1 LPM)
Alarms:	High gas
Display:	digital
Accuracy:	± 1% full scale
Repeatability:	± 1% full scale
Zero drift at constant temp:	5%/7 Days
Zero drift temp effect:	0.3%/°C
Operating temp range:	32-104 °F (0-40 °C)
Storage temp:	not specified
Weight:	12.1 lbs. (5.5 kg)
Dims:	7.25x7.8x15 in. (185x220x390 mm)
Output signal:	0-100 mV
Calibration:	daily/not specified
Cal controls:	zero span

TEST RESULTS: This unit was given zero drift tests over an 8-hour period. On 120Vac, the unit had 0.1% drift and a second test showed no measurable drift when on battery operation for the same time.

COMMENTS: This unit was heavy with an unusual shape and costly, but its performance is excellent. Cost and size excluded it from consideration for this project.

Shimadzu Scientific Inst. Inc
7102 Riverwood Drive
Columbia, MD 21046
(800)-477-1227
Fax (301)-381-1222

Model:	CGT-10-3A
Price:	$9500.00
Method:	NDIR
Ranges:	dual up to 100% in 1/5 ratio
Power:	115Vac only
Sampling Pump:	internal @2.5 LPM
Alarms:	none
Display:	analog
Accuracy:	± 2% of full scale
Repeatability:	± 2% of full scale
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	5-40 °C
Storage temp:	not specified
Weight:	15 kg
Dims:	23x20x45 cm.
Output signal:	0-1Vdc
Calibration:	not specified
Cal controls:	not specified

TEST RESULTS: none

COMMENTS: no battery option.

Siemens Industrial Automation, Inc.
100 Technology Dr.
Alpharetta, GA 30202
(404)740-3932
Fax (404)3998

Distributor:
Flow Tech
Hunt Valley, MD

Model:	ULTRAMAT 21/O_2
Price:	$4600.00
Method:	NDIR
Ranges:	0-10%
Power:	120Vac only
Sampling Pump:	Internal
Alarms:	2 per channel
Display:	digital
Accuracy:	± 1% of reading
Repeatability:	± 1% of reading
Zero drift at constant temp:	0.2% of range per week
Zero drift temp effect:	not specified
Operating temp range:	not specified
Storage temp:	not specified
Weight:	20 lb (9 kg)
Dims:	17.2x6.6x11.4 in. (44x17x29 cm)
Output signal:	analog 0-20ma
Calibration:	zero/daily; span/yearly
Cal controls:	zero/span

TEST RESULTS: A 21/02 analyzer with 0-20% CO2, 0-25% O_2 and 0-20 ppm CO ranges was tested 10/4 to 10/6 '94. A 20% CO_2 cal gas would be needed to set/check the span and none was available, so the unit was tested using its as received span setting. The unit was evaluated with a 5% CO_2 gas using the STEC gas divider to make dilutions. The test results were excellent. The unit was tested with 10 ppm CO/2540 ppm CO_2 and gave excellent results. Short term repeatability was exact over the 0-5% range.

COMMENTS: The unit must be autocaled daily with zero gas for good low level accuracy and again whenever the environmental conditions change. The unit, with 3 analyzers , is very heavy. It must be operated in the horizontal, on a flat surface. A short 2 in. drop test showed zero deflection of the display.

Telaire Systems, Inc.
6489 Calle Real
Goleta, CA 93117
(800)472-6075
(805)964-1699
Fax (805)964-2129

Distributor:
Jo Mitchel
P J Envirolytics
Hamburg, N.J.
(201)209-1444

Model:	1050 CO_2 Monitor
Price:	$500.00
Method:	NDIR
Ranges:	0-1999 PPM
Power:	Battery with 115Vac recharger operation
Sampling Pump:	none/diffusion
Alarms:	user set single point alarm
Display:	digital
Accuracy:	± 50 ppm
Repeatability:	± 20 ppm
Zero drift at constant temp:	100 ppm/year
Zero drift temp effect:	not specified
Pressure dependence:	+0.19% reading per mm Hg.
Operating temp range:	32-122 °F (0-50 °C)
Storage temp:	140 to 140 °C (-40 to 60 °C)
Weight:	22 oz. (624 gm)
Dims:	7.5x3.8x3 in. (19x9.7x7.6 cm)
Output signal:	0-2Vdc @ 0-1999 PPM (2-4Vdc @ 2000-5000 PPM)
Calibration:	? yearly ??
Cal controls:	zero/span

TEST RESULTS: none

COMMENTS: This unit does not cover desired range, but has a very attractive price. The vendor will not supply loaners nor help in finding a local user (they are not computerized to search a user file).

Teledyne Brown Engineering, Inc.
Analytical Instruments
16830 Chestnut St.
Box 1580
City of Industry, CA 91749-1580
(818)961-9221
Fax (818)961-2538

Model:	730 Series
Price:	$3450.00 and up
Method:	NDIR
Ranges:	0-10% and others
Power:	115Vac, can supply a 24Vdc power version
Sampling Pump:	?
Alarms:	none/?
Display:	digital
Accuracy:	± 2% F.S.
Repeatability:	± 1% F.S.
Zero drift at constant temp:	1% F.S./week
Zero drift temp effect:	
Operating temp range:	5 to 45 °C(41-113 °F)
Storage temp:	
Weight:	20 lb
Dims:	models vary
Output signal:	4-20mAdc, 0-1Vdc
Calibration:	daily/?
Cal controls:	?

TEST RESULTS: none

COMMENTS: This sensor is used in the Hamilton Standard space backpack to replace the old Beckman sensor.

COMPANIES CONTACTED BUT ANALYZERS REJECTED

The companies listed below were contacted for the CO_2 analyzer survey, but their units were rejected for various reasons.

1. AIM USA
   P.O. Box 720540
   Houston, TX 77272-0540
   (800)274-4246
   Hand held but do not do CO_2.

2. Bachrach, Inc.
   625 Alpha Dr.
   Pittsburgh, PA 15238-2878
   (412)963-2157
   Their units are for stack gas monitoring primarily.

3. Biosystems, Inc.
   5 Brookside Dr.
   Middlefield, CT 06455
   (203)344-1079
   Their units do not do CO_2.

4. Bruel & Kjaer
   185 Forest St.
   Marlborough, MA 01752
   (508)-481-7000
   An in-house demonstration of the B & K Model 1302 analyzer was a complete failure. No consideration was given to this unit following the demo.

5. Columbus Instruments
   Columbus, OH
   (614)488-6176
   Their "Ferm-180" is 115VAC, high accuracy/high sensitivity unit for 0-15% CO_2/0-20% O_2. No portable units.

6. COSMOS/Sam Dick Industries, Inc.
   1140 N.W. 46th St.
   Seattle,WA 98107
   (206)789-5410
   Fax (206)7895414
   An interesting device that uses a sensitive thermal conductivity detector to measure the composition of one gas in another. It is non-specific so of no use in this study but may be a simple easy-to-use item to replace a total hydrocarbon analyzer.

7. Enviro Systems Ltd.
Electron House
Higher Hilgate Stockport
Cheshire SKI 3QD England
44(0)61 474 7477
They make a unit which can measure NH3, formaldehyde, etc. of unspecified methodology. It is not applicable to this program, but might apply to a program to quantitate special species not generally found by the normal test procedures.

8. Foxboro Co.
P.O. Box 500
East Bridgewater, Ma 02333
(508)-378-5556
These units are too large and do not cover the 7.5% range.

9. GAC/General Analysis Corp
140 Water St.
South Norwalk CT 06854
(203)-852-8999
They do not have a portable unit and do not want to make one. Their fixed unit was too large to be moved easily.

10. Gasalarm Systems Corp.
Houston, Texas
(713)-364-1988
They do not have an off the shelf fixed or portable unit for this application.

11. HNU Systems, Inc.
160 Charlemont St.
Newton, MA 02161-9987
(800)724-5600
They make PID's & portable GC's, not germane to this study.

12. IMR/Environmental Equipment, Inc.
5401 Central Ave.
St. Petersburg, FL 33710
(813)328-2818
A nice looking stack gas analyzer of no interest.

13. MDA Scientific, Inc.
Evanston, ILL
(800)344-4632
They do not make any CO_2 analyzers.

14. MTI/Microsensor Tech. Corp.
41762 Christy St.
Fremont, CA 94538
(510)-490-0900
Portable GC for fixed gas analysis. Too $ and complicated.

15. Neotronics
2144 Hilton Dr. SW
Gainsville, GA 30501-6153
(800)-535-0606
This company did not reply to a request for information.

16. Penn-Del Inst. Sales Inc.
709 Bethlehem Pike
Philadelphia, PA 19118
(215)-836-9100
Tested Horiba Model APBA-210 in house. Unit does not cover the 7.5% range and showed poor performance and poor zero stability.

17. Photovac, Inc.
25-B Jefryn Blvd. West
Deer Park, NY 11729
(516)254-4199
These units are portable hand held gas chromatographs that are too complicated for the specified use.

18. Rosemount Analytical Inc.
600 South Harbor Blvd.
Le Habre, CA 90631
(213)-690-7600
No portables. No movable fixed units.

19. Sierra Monitor, Inc.
1991 Tarob Ct.
Milpitas, CA 95035
(408)262-6611
No portable units; remote sensors & controllers only.

20. Teledyne Analytical Instruments, Inc.
Pasadena, CA
(818)961-9221
Most of their units are combustion analyzers that do not measure CO_2 directly, but calculate it from a combustion equation. Not applicable to this study. Their "Mini-IR" sensor does apply.

21. Thermal Environmental Inst. Inc.
8 West Forge Pkwy.
Franklin, MA 02038
(508)-520-1460
Low range, large, expensive, fixed units only.

22. Universal Sensors, Inc.
5258 Veterans Blvd.
Mt. Airie, LA 70006
(504)885-8443
They do not make a portable CO_2 analyzer.

APPENDIX B: FIELD TESTING PROTOCOL.

FIELD TESTING INFO FOR SUBMARINE PORTABLE CO_2 ANALYZER

NMRI POC: Dr. Richard Lillo
Naval Medical Research Institute
Code 541
8901 Wisconsin Ave.
Bethesda, MD 20889-5607
(301) 295-5883/-5882
DSN 295-5883/-5882

1. Background

NMRI was tasked by NSMRL to identify a portable CO_2 analyzer for use on U.S. Navy submarines. This task involved a market search, instrument testing in the laboratory, and now field testing of the candidate analyzer, the Geotechnical Infra-red Analyzer. This analyzer measures CO_2 up to 7.5%.

2. Your job

Your job is to help us by performing the field test which will be done on at least one U.S. sub. Results from your testing will help to evaluate:

a. how "sailor friendly" the analyzer is
b. stability of instrument under actual sub conditions
c. potential problems with draft procedures
d. comparison of analyzer and CAMS-I CO_2 measurements

3. Equipment

a. 1 Geotechnical CO_2 analyzer for 1 ATA use
b. Battery charger for analyzer
c. Sampling tubing
d. Data sheets

4. Test Plan

a. Check calibration (do not recalibrate) once a day prior to use.
b. Following calibration check, take CO_2 measurements throughout the sub spaces.
c. Record (when possible) simultaneous CAMS-I readings for spaces where portable CO_2 analyzer is used.

Instrument procedures

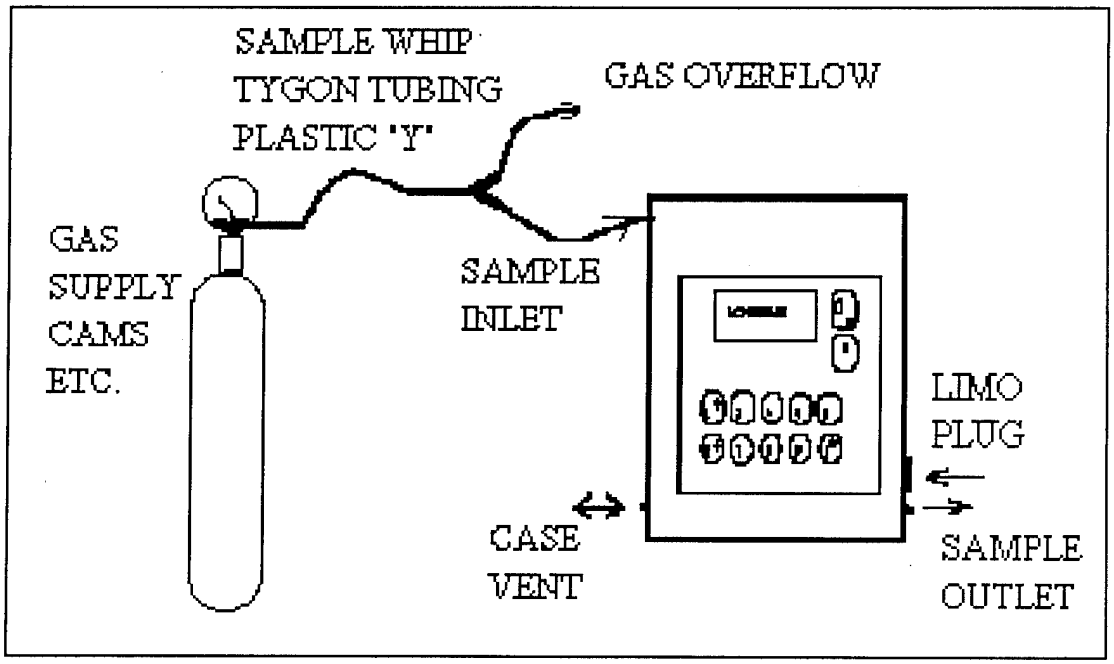
Batteries/charging.

The CO_2 analyzer is normally run off its self-contained NiCad batteries. However, when the batteries require charging, the analyzer can be used when it is attached to the charger. The charger plugs into 110 volt line current. The instrument must have batteries in place to operate. Ideally, NiCad batteries should be fully discharged and recharged during operation rather than continually topped off without a full discharge. However, this probably will not be possible - don't worry. An overnight charging should provide 12 h of usage.

Calibration check.

1. Instrument has been calibrated at NMRI. Do not recalibrate.

2. Locate the CAMS-I calibration gas and install on its regulator the tubing we have supplied. This tubing contains a tee to allow sampling with the analyzer. Connect the inlet port of the CO_2 analyzer to the side branch of tubing so that calibration gas can be sampled without pressurizing the analyzer.



3. Purge the CAMS-I regulator 3 times to insure removal of all ambient air from the regulator; then dial in a delivery pressure of several psig. Leave gas cylinder turned on but secure flow using the regulator outflow valve.

4. Turn on analyzer by pressing the red key. The LCD will show the company name, model no., and information on key functions.

5. Press the "0" key to exit that screen. The LCD display will show the following choices:

1-General Utilities
2-Read Gas Levels
3-View/Print/Analyze
4-Download Data

6. Press "1" for General Utilities. The display will show the following:

1-Check Time/Date
2-Battery Status
3-Memory
4-Calibration 0-Exit

7. Press "2" to read the available battery capacity. If there is insufficient charge, attach analyzer to charger that is run off 110 volt line current and a) charge for at least 1 hour or b) use while charging.

8. Press "0" twice and then "2" to read gas level. Press "5" to turn on pump. Analyzer is now measuring CO_2. Allow to warm up for 5 min.

9. Open the CAMS-I regulator valve and adjust gas flow so it is just audible as it exits the tubing.

10. Wait at least 1 min for reading to stabilize. Record reading at top of daily data sheet.

11. Shut off calibration gas flow.

12. Close valve on CAMS-I cylinder and bleed regulator down.

13. Leave analyzer on. Analyzer can now be moved about the sub to measure CO_2.

14. For each reading, use a separate line on the data sheet. Include any comments on the bottom.

15. When finished turn analyzer off by pressing red key.

16. Subsequent sampling for CO_2 during the same day can be done without repeating calibration check. Simply turn on the instrument by pressing the red key, press "0", then "2", then "5"; allow to warm up 5 min before using.

NMRI

CO2 Sampling Data Sheet

(Use New Sheet Each Day)

CO2 Unit: Geotech CD500LB Date: _____

Time On: _____ Submarine: _____

Operator: _____

CO2 Concentration in CAMS Gas:_____(%)

Geotech CAMS Gas Reading: _____(%) Time Checked:_____

(DO FIRST EACH DAY)

Time	Location	CAMS-1 Reading (Torr)	Pressure (Torr)	CAMS-1 CO2 (%)	Geotech CO2 (%)
	Torpedo Room				
	Crew's Mess				
	Battery Exhaust				
	Fan Room				
	Missile Room				
	R-12 Plant				
	Tunnel				
	CO2 Scrubber				
	AMR2				
	R-114				
	Engine Room				

Notes:

APPENDIX C: OPERATING PROCEDURES FOR THE RECOMMENDED ANALYZER, GEOTECHNICAL CDM-1000/LONG.

Sufficient information is provided here to calibrate and measure CO_2 onboard a submarine. It is assumed that the calibration gases will not be onboard and that the user will have calibrated the unit prior to going onto the submarine. This was the rationale behind the 90-day testing during which the instrument was not recalibrated. Other instrument functions are available which can be accessed via the menu but won't be discussed here.

Batteries/charging

The CO_2 analyzer is normally run off its self-contained NiCad batteries. However, when the batteries require charging, the analyzer can be used when it is attached to the charger. The charger plugs into 110 volt line current. The instrument must have batteries in place to operate. Ideally, NiCad batteries should be fully discharged and recharged during operation rather than continually topped off without a full discharge. However, this probably will not be possible. An overnight charging should provide 12 h of usage.

Calibration and Use

1. Calibration should be done at temperatures 18 to 24 °C (65 to 75 °F).

2. Required gases with high-purity (stainless steel diaphragm) regulators to allow adjustment of gas flow down to several liters/min:

a. Zero gas = CO_2-free, hydrocarbon-free air

b. Span gas = 7.5% CO_2, balance hydrocarbon-free air, primary standard certified to $\pm$ 1% relative.

3. Purge both regulators 3 times to insure removal of all ambient air from the regulator; then dial in a delivery pressure of several psig. Leave gas cylinder turned on but secure flow using the regulator outflow valve.

4. On both regulators, install tubing (e.g., Tygon, nylon, Teflon) that contains a tee to allow sampling with the analyzer.

5. Turn on analyzer by pressing the red key. The LCD will show the company name, model no., and information on key functions.

6. Press the "0" key to exit that screen. The LCD display will show the following choices:

1-General Utilities
2-Read Gas Levels
3-View/Print/Analyze
4-Download Data

7. Press "1" for General Utilities. The display will show the following:

1-Check Time/Date
2-Battery Status
3-Memory
4-Calibration 0-Exit

8. Press "2" to read the available battery capacity. If there is insufficient charge, attach analyzer to charger that is run off 110 volt line current and a) charge for at least 1 hour or b) use while charging.

9. Press "0" to return to the previous screen. Press the "4" key to calibrate. Press "5" to start pump. Allow to warm up for 5 min.

10. Connect the inlet port of the CO_2 analyzer to the side branch of the Span gas tubing so that calibration gas can be sampled without pressurizing the analyzer (in similar fashion as with NMRI testing in Fig. 1 of this report).

11. Open the Span gas regulator valve and adjust gas flow so it is just audible as it exits the tubing.

12. Wait at least 1 min for reading to stabilize. If reading is within 0.20% of the calibration gas (e.g., 7.50 $\pm$ 0.20%), calibration is unnecessary, shut off calibration gas flow, and go to step #17.

13. If calibration is necessary, press "1" to calibrate and then enter CO_2 concentration (e.g., 7.50%). To backspace over an entry mistake, press and hold "0".

14. Press "0" to exit screen and then "1" (i.e., "Yes") to calibrate.

15. Observe readout. Meter reading should be within 0.20% of the calibration value. Calibration can be repeated if desired.

16. Shut off Span gas flow.

17. Press "0" twice and then "2" to read gas level. Press "5" to turn on pump. Analyzer is now measuring CO_2.

18. Remove span gas tubing and attach Zero gas tubing to analyzer.

19. Open the Zero gas regulator valve and adjust gas flow so it is just audible as it exits the tubing.

20. Wait at least 1 min for reading to stabilize. If reading is not within 0.20% of 0, instrument should not be used unless this problem is corrected.

21. Shut off Zero gas flow, close valves on both gas cylinders, and bleed down regulators.

22. Turn analyzer off by pressing the red key and remove Zero gas tubing. Instrument is now calibrated and NMRI testing indicates analyzer should be useable for up to 90 days without recalibration with estimated accuracy $\pm$ 25% relative.

23. Analyzer can now be moved onto the submarine to measure CO_2. Simply turn on the instrument by pressing the red key, press "0", then "2", then "5"; allow to warm up 5 min before using.